THE EFFECT OF PLANT DENSITY AND NITROGEN FERTILIZATION

ON YIELD AND MINERAL CONSTITUENTS OF

TWO MAIZE VARIETIES GROWN IN HAWAII

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INTRODUCTION

Maize or Indian Corn (*Zea mays* L.) is believed to have originated from the New World (Moore, 1960). The Food and Agriculture Organization (F.A.O.) report (1961) listed world maize production at 224,200,000 metric tons, which quantitatively ranked it third among the cereals in production following rice and wheat. Nevertheless, it is unequalled in efficiency of conversion of solar radiation into food for human beings and feed for livestock. Coursey and Haynes (1970) noted that maize can produce 200 x 10^3 calories per hectare per day as compared to 176 x 10^3 for rice, 110 x 10^3 for wheat and 114 x 10^3 for sorghum. When maize was compared with root crops such as cassava, yams, or cocoa yams, Oyolu (1972) found it to have higher efficiency of dry matter production and higher levels of minerals and proteins.

Maize cultivation spread from the New World to the humid tropics, subtropics and other regions of the world which receive adequate rainfall or supplemented by irrigation and have ample solar radiation. The yield of maize is a function of plant population, level of soil fertility and genetical potential interacting with the environment. The objectives of many experiments that have been reported in the literature were to establish the optimum rate of fertilizer nitrogen and planting density for maximum attainable yield of maize. However, most of these experiments were conducted in the temperate regions using adapted varieties. Bunting (1973) noted that studies of plant densities in relation to grain yield have been restricted to a narrow range in North America, whereas, elsewhere grain yields at densities ranging beyond 10 plants/m^2 have not been reported. As new high-yielding, disease and lodging resistant varieties are developed, a need arises for adjustments in the rate of fertilizer application and planting density to meet the higher demands of the new hybrids.

Since the early 1970's many sugar cane and pineapple lands in Hawaii have been "abandoned" due to economic considerations. Research is being conducted to determine profitable replacement crops on these lands. In 1974 the discontinuation of sugar cane production at Kohala, which is situated at the northwest region of the Big Island of Hawaii, released approximately 14,000 acres of agricultural land with a well established irrigation system for possible diversified agriculture. The College of Tropical Agriculture at the University of Hawaii was called upon by the County and State of Hawaii to research the feasibilities of producing maize and other feed crops as substitutes for sugar cane. Also, since the use of maize as feed for livestock has increased, more information is needed on forage quality components as influenced by plant population and the rate of fertilization. Most of the mineral uptake and nutrient accumulation studies of maize were conducted at either several levels of nitrogen fertilization at fixed plant density or at several plant densities with fixed N level.

The objectives of this study were to update available information on the effects of nitrogen rate and plant spacing, within rows, on the yield and its components of two tropical maize hybrids (Pioneer 304B and the University of Hawaii's H-688) grown on land that was previously used for sugar cane production at Kohala. These objectives included collection, analysis and study of data on the following:

1. Forage yield, its components and quality,

2. Grain yield, its components, and grain to forage ratio,

3. Growth parameters affecting grain and forage production,

4. Leaf mineral composition.

LITERATURE REVIEW

Variety

The maize hybrids which were first developed in the U.S.A. during the early 1930's proved to have superior production capabilities than the open pollinated varieties. Duncan (1954) noted that the outstanding hybrids were those which allowed the effects of favorable weather, and proper management to be fully expressed in high grain yields and quality. In addition to a high potential for forage and grain yields, these hybrids should be adaptable to early or late maturation, resist lodging insects and disease attacks, and have tolerance to cold and heat stresses. And above all, their percent oil and protein should be high. Brewbaker (1976) noted that none of the hybrids commonly grown on the mainland U.S.A. could produce economically in Hawaii due to their susceptibility to diseases and insects encountered in the tropics such as mosaic virus, rust, leaf blight, kernel rot, brown spot, ear worms and leaf hoppers.

According to Aldrich and Leng, (1972) good standing ability, which is a heritable characteristic in maize, is achieved by using hybrids which are tolerant to crowding and resistent to root and stalk rot organisms.

Quality and yield in terms of dry matter distribution to the cob and protein content has been reported by some workers to be due to heritable traits (Kirshnamurthy et al, 1974). Gonske and Keeney (1969) using three Wisconsin single cross maize hybrids, noted significant differences in dry matter yields. They attributed this to the relative maturing time of the different hybrids. Goldsworthy (1972) attributed differences in grain yield to relative size of grain of the different varieties which was independent of the plant population used.

Nitrogen

Duncan (1954) showed that the optimum yield of hybrid maize could not be attained when soil fertility was inadequate. This and other similar reports (Fox, 1973; Sharma and Sood, 1974) underscore the importance of nitrogen fertilization. According to Zuber et al., (1954) about 3/4 lb/bu of maize is protein. To attain this quality, an application of additional 1/2 lb of nitrogen is normally required. Cnly extremely fertile soils can deliver this quantity of nitrogen in a single growing season. Nitrogen is, therefore, often a limiting factor in maize production, and becomes more so when it is grown in thick stands. Various workers (Gonske and Keeney, 1969; Nelson and MacGregor, 1973; Kamprath et al., 1973) obtained significant yield increases by increasing the rates of nitrogen fertilization. Fox (1973) using a continuous function experimental design in nitrogen fertilization of sweet corn obtained a linear yield response to applied nitrogen rates up to 200 kg/ha. At low rates he observed a "diluting effect" on the leaf nitrogen. Sharma and Sood (1974) obtained a typical Mitscherlich type of response curve to N with sweet corn and pop corn.

Lang et al. (1956) attributed increases in yield at high nitrogen fertilization to three adjustments:

1. Production of two or more ears per plant,
2. Increase in size of ears and
3. Reduction of percentage barrenness.

Numez and Kamprath (1969) pointed out that grain yield per plant was dependent upon the leaf area per plant. The efficiency of a given leaf area to produce grain was higher as nitrogen rate increased.

The optimum amounts of nitrogen required for economic optimum yield of maize vary from region to region and depends upon season, soil type, variety and planting density. Chamberland (1975) who conducted nine field trials from 1971 to 1973 with six Quebec soils, felt that 100 kg N/ha were optimal except under adverse conditions. In such cases he recommended rates of 220 to 225 kg N/ha. Phipps and Pain (1975) observed that in most European countries, rates of N application reached up to 150 kg/ha and in the U.S.A. responses to 200 kb N/ha for forage maize are common. In India, Sharma and Sood (1974) obtained economic optimum yield of sweet corn and pop corn with rates of 60 kg N/ha. Hag and Ten (1975) reported 200 to 300 kg N/ha for forage as adequate and 140 to 169 kg N/ha for grain maize in Lelystad, Netherlands. In Hawaii rates for maximum attainable yield vary fro 140 to 210 N/ac depending on the hybrid and soil fertility (Brewbaker, 1976; Fox, 1973; Tamimi, et al, 1977). For many soils of Eastern Nigeria 200 lb N/ac are commonly used.[1]

Some growth characteristics and quality of maize are affected by the rate of nitrogen fertilizer application. Aldrich and Leng (1972) showed that lodging increases with higher nitrogen rates. Reports from several experiments showed that crude protein, oil content of grain and stover of maize increased with increasing amounts of nitrogen fertilization (Lang et al., 1956: Latkovics, 1974). The increase was higher in the stover

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[1]Personal experience with the Ministry of Agriculture, Enugu, Nigeria

than in the grain. Zuber et al. (1954) obtained an increase in crude protein content of the grain from 7.25% for the control as compared to 8.83% due to application of 134.5 kg N/ha.

Fertilizer nitrogen requirement for maize when grown for forage is greater than when grown for grain. The nitrogen and protein contents in the forage depend on the levels of nitrogen applied, plant density and time of harvesting. Thick planting, low nitrogen rate and late harvesting decreased protein content of forage. Miaki (1967) working with two rates of nitrogen and different harvesting dates, obtained the highest protein contents from fodder cut at the boot stage to which 180 kg/ha of N was applied. Lowest crude protein content was obtained at milk stage with 60 kg/ha of N. In Hawaii Sherrod et al. (1968) obtained highest levels of nitrogen in the tissue of whole plant harvested at the silk stage, but they found no significant change in nitrogen content between the milk and early dent stages of maturity. Generally, harvesting at the dent stage of maturity for silage was recommended.

Plant density

Proper planting density for maize is very important because it is less capable of adjusting to poor stand than most other cereals. Many experiments have been reported to show that when population exceeds a certain limit, yield decreases per given area. First, the decrease in yield per plant is offset by the increase in plant number per unit area, with further decrease in yield per plant the economic optimum is passed and a net decrease results. Thomas (1956) maintained that increasing plant density decreased the average weight of ears, regardless of further increases in nitrogen fertilization. Many workers attributed the reduction in yield to narrow row spacing (Colville and Burnside, 1963; Singh, 1972) while others (Giesbrecht, 1969; Brown et al., 1970) reported no significant effects. Robertson et al. (1968) concluded that yield of ear maize was not influenced by plant density. On the other hand, optimum spacing may not only reduce competition between plants but it could result in better utilization of radiant energy hence, increase yield. Prine and Schroder (1964) pointed out that high plant population leads to competition among plants and decreases in leaf area and in yield of grain per plant.

Optimum rates of planting vary widely from country to country depending upon season and soil type. General recommendations regarding planting density have been made in many countries after many years of maize cropping. Giesbrecht (1969) found that 60,000 to 75,000 plants/ha was about optimum for the northern limit of the United States corn belt. Colville et al. (1964) recommended planting rates of 12,000 to 24,000 plants/ac in humid areas and 6,000 to 12,000 plants/ac in non-irrigated, semi-arid regions. In Northern Europe 6-8 plants/m^2 are commonly recommended as an adequate plant population for grain production (Zscheischler and Gross, 1966). In India, Sharma and Gupta (1968) got maximum yield with a density of 60,000 plants/ha. According to Villanueva (1971) recommended rates in the Philippines range from 50,000 to 60,000 plants/ha, while in Nigeria under a mixed cropping system (personal experience), 20,000 plants/ha is commonly practiced. Army and Green (1967) claimed that if all other growth factors were optimum, then it would be possible to attain 400 bu of grain/ac with a population of 150,000 plants/ac. Boney and Yaneva (1975) obtained maximum grain-fodder yield at a planting density of 600,000 plants/ha and recommended a planting density of 300,000 to 600,000 plants/ha without inter-row cultivation for maize. Comparing two low-land tropical varieties Tuxpeño planta baja and Tuxpeño crossed with Eto planta baja, Goldsworthy (1972) obtained increasing grain yields with plant population up to 150,000 plants/ha which is three times the population at which breeders normally carry out their selection.

The maize plant makes many adjustments to increasing populations. These adjustments are reflected in the ear size, weight and quality, plant height, lodging and percentage stalk barrenness. Robertson et al. (1968) observed that ear weight and quality decreased with very high population. Similar results have been reported by Lang et al. (1956) and were confirmed by Buren and Anderson (1970). Brown (1961) working with thick stands of corn in Connecticut obtained 62% lodging at 86,000 stalks/ac, 31 and 4% with 52,000 and 30,000 plants/ac respectively. He recommended early harvest (as a green crop) as means of minimizing lodging. Giesbrecht (1969) reported increases in plant height and lodging with increasing population which he attributed to shading effect thus causing rapid growth and weaker plants. Accroding to Lang et al. (1956), stalk barrenness was influenced more by high plant densities than either nitrogen fertilization or hybrid, and believed that increasing percent barrenness was a direct consequence of retardation in silk emergence at high population rates. Dungan et al. (1958) reported 22, 31, 39 and 46% lodging at 8,000, 12,000, 16,000 and 20,000 plants/ac respectively when he planted more than one plant/hill. Giesbrecht (1969) observed increases in barrenness from 3 percent at 30,000 plants/ha to 15 percent at 75,000 plants/ha. He attributed this percentage increase to moisture stress. Earley et al. (1966) observed increasing barrenness with artificial reduction of normal summer sunlight, which he compared to the effects of shading caused by dense plant population.

In summary of maize plant characteristics affected by plant density, Nelson (1956) noted that increasing plant density also increases the tendency for barren stalks and lodging, but decreases the number of ears per stalk in multiple ear varieties, and has little effect on shelling percentage.

Interactions between and among nitrogen, spacing, variety and season

Nitrogen x spacing x variety interactions in maize have been extensively studied by many researchers (Duncan, 1954; Lang et al. 1956; Numez and Kamprath, 1969). Proper planting dates are important for high maize yields due to its positive response to solar radiation. In Hawaii, planting in April through May usually provides the highest temperatures and solar radiation for the plants and that is when the greatest stover and grain yields are obtained. Villanueva (1971) comparing two dates of planting (May and July) and using three varieties realized the highest yield with Waimea Dent planted in May.

Effect of nitrogen rate and plant spacing on mineral constituents of maize

Mineral composition of maize leaves at silking time has been widely utilized to indicate which of the nutrient elements would be limiting to plant development and yield. Review of plant analysis literature showed that not much attention has been paid to uptake of macro- and micro-nutrients of field maize as affected by increasing nitrogen rates with varying plant density. Hansen (1972) working with barley grown in pots obtained increases in nitrogen, potassium and total cation concentration in tissue with increasing rates of nitrogen. In a maize pot experiment fertilized with 0, 100 and 200 kg of N/ha and 0, 80, 160 and 240 kg of P/ha, Sawarkar and Nayar (1975) obtained increases in plant nitrogen content with both increasing rates of N and P fertilizers. Plant sulfur content was only increased due to N application. Shukla (1972) also obtained significant increases in leaf N% with increasing rates of N fertilizer applied. Phosphorus content was reduced while leaf K% increased significantly. These findings are in agreement with those of Barber and Olson (1968) and Terman et al. (1974), who reported that high levels of nitrogen fertilization lead to enhanced uptake of N, P, Ca, Mg, Mn and Zn in both maize leaves and forage tissue. Walker and Peck (1973) suggested that increases in mineral uptake with increasing N rates may be due to enhancement or root growth which stimulates efficient ion uptake.

MATERIALS AND METHODS

An experiment to evaluate the effects of nitrogen rate x plant spacing x variety on maize yield, its components, and on mineral content of leaves and forage during two growing seasons, was conducted at the Kohala Experimental Station on the Island of Hawaii. The soil at the experimental site is silty clay which belongs to the Kohala series, of the order Inceptisols (Sato et al, 1973; see also Appendix). The station is at an elevation of 122 meters. The average annual rainfall is between 102 and 152 cm on the windward side of the Kohala Mountains. The rainfall is unevenly distributed during the year, most falling during the winter months. Certain climatic data are reported in Table 1.

The two tropical hybrids of maize used in this experiment were Pioneer 304B, which is a common commercial hybrid, and H-688 which was recently developed by the University of Hawaii. Nitrogen was applied at rates of 78.4 (low level), 156.8 (medium level) and 313.6 kg/ha (high level). Prior to initiating the experiment, the site was irrigated daily with 5 cm of water for a period of one week to leach out the residual soil nitrate in the root zone. Nitrogen fertilizer was applied in a split application where half of the total was broadcasted and roto-tilled into the soil at the time of planting; and the remaining half was top dressed 6 weeks after planting. Urea was the source of nitrogen. The three within row spacings used were 22.9 (low), 15.2 (medium) and 11.4 cm (high). The inter-row width of 76.2 cm was constant. These arrangements were equivalent to .174, .116 and .087 m^2/plant or 57,408, 86,111 and 114,815 plants/ha respectively (Table 2).

Table 1. Summary of data on aero-climatic factors at the experimental site at Kohala during the growth period

Temp.[a] Min. °C	Temp.[a] Max. °C	Rainfall 1st Crop cm	Rainfall 2nd Crop cm	Mean Solar Radiation[a] g cal cm^{-2} day^{-1}	Relative Humidity[b] Min. %	Relative Humidity[b] Max. %	Wind[c] km/hr
21.1	27.4	47.4	20.2	445	66.8	100	16

(a) Data collected for Crop II, (planted Aug. 3, 1977 and harvested Nov. 30, 1977).

(b) Relative humidity reached 100 per cent occasionally at night or following heavy rainfalls.

(c) Wind was occasionally N.E. or S.E. but rarely from a southerly direction.

Table 2. Experimental variables and design to determine the effects of plant spacing and N fertilizer rates on yield of two corn varieties at Kohala. (76.2 cm between rows).

In-row plant Spacing	Plants/ha	Nitrogen Rate kg/ha
22.9 cm	57,406	78.4
		156.8
		313.6
15.4 cm	86,109	78.4
		156.8
		313.6
11.4 cm	114,813	78.4
		156.8
		313.6

4 replicates

The experimental design was a split plot complete factorial with 3 nitrogen x 3 spacing x 2 varieties and 4 replications (Table 3). Nitrogen and spacing were the main plots and variety the subplots. All treatments were randomized within the four replicates. Plot sizes were 9.15 m by 6.10 m with four rows per variety. Block (replicate) sizes were 27.44 m by 18.29 m.

The soil was analyzed for pH, P, K, Ca, Mg, organic matter, and cation exchange capacity (C.E.C.) prior to planting and after the first and second harvests. Soil samples were collected using a soil probe from the top fifteem cm of each of the 36 plots. Eight or more subsamples per plot were collected using the snake (S) technique and bulked into one composite sample. These were mixed thoroughly and a representative sample of 1 kg was taken, placed in labelled double plastic bags then tied and saved for future analyses.

All soil samples collected were sieved through 20-mesh screen. Between 25 and 30 g of sieved soil per sample were used for moisture determinations. The determination of pH was by glass electrode pH meter using soil paste in distilled water. Readily available phosphorus was extracted using modified Truog method (Ayres and Hagihara, 1952). Color was developed for ten·minutes by the phospho-molybdate blue technique and read on a Klett Summerson colorimeter. Exchangeable cation (K, Ca, and Mg) were extracted with 1N ammonium acetate (NH_4CAc) adjusted to pH of 7 and determined on an atomic absorption spectrophotometer. Organic matter was determined by a modified Walkley and Black (1934) method. The C.E.C. was determined separately by two methods: using 1N NH_4Cl solution or 1N NH_4OAc solution adjusted to the pH of the soil (Tamimi, et al., 1972), followed by displacement with KCl and distillation of NH_3. The value

Table 3. Analysis of various tables for effect of plant density and N fertilization on yield of two corn varieties at Kohala

Source of variation	d.f.
Reps	3
Main plots (N-spacing)	(8)
N rate	2
spacing	2
N x spacing	4
Error (a)	24
Sub plots	
Variety	1
Var x N	2
Var x spacing	2
Var x spacing x N	4
Error (b)	27
Total:	71

reported is the mean of the two methods.

Confirmation of results was obtained by running duplicates on 10% of all samples. Table 4 shows the results of soil pH, and levels of P, K, Ca, and Mg in these plots were at adequate levels for good corn production. This is based on results of several experiments on this site conducted by Dr. Y. N. Tamimi and his coworkers, where the following levels are considered optimum: pH, 5.5; P, 50 ppm; K, 200 ppm; Ca, 1200 ppm; and Mg, 250 ppm.

Sutan (S-Ethyl diisobutylthiocarbamate) was applied as a pre emergence herbicide at a concentration of 18.7 ml/l of water at a rate of 375 l/ha, and was incorporated into the soil. At time of planting Atrazine (2-chloro-4-ethylamino-6-isopropyl-amino-1,3,5-trazine) was sprayed at a concentration of 2.2 kg/ha in 75 l of water. Subsequently weeding was conducted by hoe as necessary. Planting was done by hand at a rate of two seeds per hill at 2.5 cm depth and the desired spacing was established using marked bamboo sticks. Two border rows surrounding the experiment were planted to act as wind breaks. Plants were thinned or replanted up to ten days after emergence to maintain the designated plant densities. As often as necessary leaf hoppers and aphids were controlled by spraying Sevin. Plots were irrigated as required with an over-head sprinkler system at the rate of 5 centimeters of water per week.

Data on solar radiation were collected only for the second crop (Table 1).

Table 4. Chemical analyses for Kohala soil at the experimental site prior to planting (0-15 cm depth)*

Soil Parameters	
pH (paste)	6.0
P	86 ppm
Ca	2150 ppm
Mg	318 ppm
K	282 ppm
Organic Matter	12.0 %
C. E. C.	15.6 m.e./100g soil

*Data reported are means of all plots.

DATA COLLECTION

Field observations

Visual observations and ratings of the following parameters were made when plants reached full tasselling stage, and prior to forage harvest: color of leaves, plant vigor, disease incidence, stalk lodging by count method. The diameters of twenty plants per variety for each plot were measured 12 cm above the ground or at the middle of the first internode. Heights of the same plant were also recorded.

Twenty-four whole ear leaves per plot for the individual varieties were sampled at full tasselling using stainless steel scissors. Weights of the fresh leaves were taken, then dried in draft oven at 65° to 70°C for 25 hours to a constant weight, from which leaf percent dry matter was calculated. The oven dried (O.D.) samples were ground in a stainless steel Wiley Mill for nitrogen and in a ball mill for other mineral analysis.

Field harvest

Harvest for forage was done when the plant reached or exceeded 45% dry matter. Two rows per plot measuring 6.1 m in length for each variety were hand harvested 10 cm above soil level for forage yield determinations. The number of plants for row 1 and row 2 were counted and recorded. Ten average plants per plot were collected, weighed fresh, chopped, mixed thoroughly and a representative sample was taken for dry matter determinations. On the average fresh sample weight had a range from 454-908 g/sample. The oven dried samples were initially ground in a stainless steel Wiley Mill and then in a ball mill for chemical analysis.

Forage yield on an O.D. basis was adjusted to the actual population per hectare. Data on grain yield was also collected from the forage harvest following the procedure described below.

Grain harvests

Two weeks after the forage harvest, the two inner adjacent rows of the two varieties were separately harvested for grain. The number of plants per 6.1 m row were counted and recorded. Ten average plants per plot were harvested and weighed fresh. The ears were husked, counted and weighed. Stover, husk and ears were chopped and mixed thoroughly and a representative sample was obtained for moisture determination. The balance of plants in each row were harvested and weighed. The ears were husked, counted and weighed. Ten representative ears were selected, weighed fresh and oven dried, then shelled. Grain and cob weights were taken for grain yield and grain to cob ratio determinations. Percentage dry matter in husked ears and in grain were calculated. Grain yield (O.D. basis) was adjusted to the actual population for each hectare and reported on the basis of 15.5% moisture. The final grain yield per hectare was a weighted average of grain yield of the forage and grain harvests. Ratio of grain yield to whole plant (forage yield) was computed on per plant basis from the two harvests.

Slightly modified procedures were used for forage and grain harvests of the second crop. Both forage and grain were harvested at the same time from the three center rows in each plot.

Chemical analysis

Tissue samples comprised of leaf and forage were analyzed for total nitrogen using Kjeldhal Method to include nitrate and nitrogen. Other minerals were analyzed using the x-ray quantometer. A check test for nitrate in the leaf and forage tissues was made using a mixture of one g of salycilic acid in 30 ml concentrated sulphuric acid. The Kjeldhal salt used was an admixture of potassium sulfate (K_2SO_4), ferrous sulfate ($FeSO_4$) and copper sulfate ($CuSO_4$) in the ratio of 10:1:0.5 respectively and 10 g of sodium thiosulphate ($Na_2S_2O_3 \cdot 5H_2O$) was added to each sample to enhance digestion. (Chapman and Pratt, 1961).

Statistical analysis

Routine analysis of variance was conducted on all parameters. Duncan's Modified Bayesian Least Significant Differences was used to determine differences between means.

RESULTS

I. THE EFFECT OF NITROGEN RATE AND PLANT SPACING ON YIELD AND YIELD COMPONENTS OF TWO MAIZE VARIETIES GROWN IN TWO SEASONS

A. Forage Yield and its Components

1. First Crop

a. Forage Yield

The first crop was planted on March 3, 1977 and harvested between July 13th and 15th, 1977. Table 5 shows the effect of three rates of nitrogen on forage yield averaged over the three rates of planting and the two varieties. Yield increased from 11.5 to 13.0 t/ha with the first increment of nitrogen, and remained constant with further increases in the nitrogen rate. The effect of interactions of nitrogen x vareity, nitrogen x spacing and nitrogen x spacing x variety on forage yield were not significant.

Forage yield increased with increasing population with the highest yield of 13.1 t/ha obtained at spacing of 11.4 cm between plants (Table 6). There were insignificant differences in yield between the medium (15.4 cm) and the closest spacing (11.4 cm). Variety H-688 produced higher forage yield than P-304B but this difference was not significant (Table 7).

b. Dry Matter Yield per Plant

Total dry matter production per plant was found to increase significantly when N rate increased from 78.4 to 156.8 or 313.6 kg N/ha (Table 5) with no significant difference in yield between the last two rates (Table 5). When the plant spacing was expressed as area per plant, dry matter production was found to increase in a linear fashion as the area/ plant was increased (Fig. 1, and Table 6). The highest and lowest yield/

Table 5. The effect of nitrogen rate on maize yield and its components planted in two seasons at Kohala

N-Rate Kg/Ha	Forage Yield (O.D.) t/ha	Grain Yield (15.5% Moisture) t/ha	Weight Per Plant (O.D.) g	Weight Per Ear (O.D.) g	Grain Yield Per Plant (O.D.) g	Grain to Whole Plant Ratio (O.D.) %	Grain to Ear Ratio (O.D.) %
First Crop							
78.4	11.5 b*	6.2 b	145 b	118 a	73 a	43.9 a	83.0 a
156.8	13.0 a	6.9 a	163 a	124 a	75 a	45.4 a	83.0 a
313.6	13.0 a	6.8 ab	162 a	119 a	77 a	43.7 a	82.2 a
Second Crop							
78.4	11.7 a	5.9 b	146 a	104 b	65 b	43.2 a	83.8 a
156.8	12.8 a	6.8 a	158 a	121 a	72 a	45.1 a	84.1 a
313.6	12.6 a	6.7 a	157 a	125 a	73 a	45.5 a	83.7 a

* Means in the same column under each crop followed by the same letter are not significantly different at P=.05 (Baye's least significant difference).

Table 6. The effect of plant spacing on maize yield and its components grown in two seasons at Kohala

Plant Spacing (Cm)	Forage Yield (O.D.) t/ha	Grain Yield (15.5% H_2O) t/ha	Weight Per Plant (O.D.) g	Weight Per Ear (O.D.) g	Grain Yield Per Plant (O.D.) g	Grain to Whole Plant Ratio (O.D.) %	Grain to Ear Ratio (O.D.) %
First Crop							
22.9	11.7 b*	6.7 a	203 a	151 a	106 a	46.8 a	83.3 a
15.4	12.7 a	6.9 a	150 b	117 b	71 b	45.7 a	82.8 ab
11.4	13.1 a	6.3 a	118 c	93 c	49 c	40.4 b	82.1 b
Second Crop							
22.9	12.0 a	6.9 a	205 a	146 a	100 a	49.1 a	84.7 a
15.4	12.4 a	6.6 b	144 b	115 b	65 b	45.3 b	83.8 b
11.4	12.6 a	5.9 c	112 c	90 c	44 c	39.6 c	83.1 c

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 7. Yield and its components of two maize varieties grown in two seasons at Kohala

Variety	Forage Yield (O.D.) t/ha	Grain Yield (15.5% Moisture) t/ha	Weight Per Plant (O.D.) g	Weight Per Ear (O.D.) g	Grain Yield Per Plant (O.D.) g	Grain to Whole Plant Ratio (O.D.) %	Grain to Ear Ratio (O.D.) %
First Crop							
H-688	12.7 a*	7.0 a	159 a	119 a	77 a	46.6 a	82.1 b
P-304B	12.3 a	6.3 b	155 a	121 a	73 b	42.1 b	83.3 a
Second Crop							
H-688	12.6 a	6.6 a	158 a	115 a	71 a	44.5 a	83.2 b
P-304B	12.1 a	6.4 b	150 a	119 a	68 b	44.8 a	84.5 a

* Means in the same column under each crop followed by the same letter are not significantly different at P ≑ .05 (Baye's least significant difference).

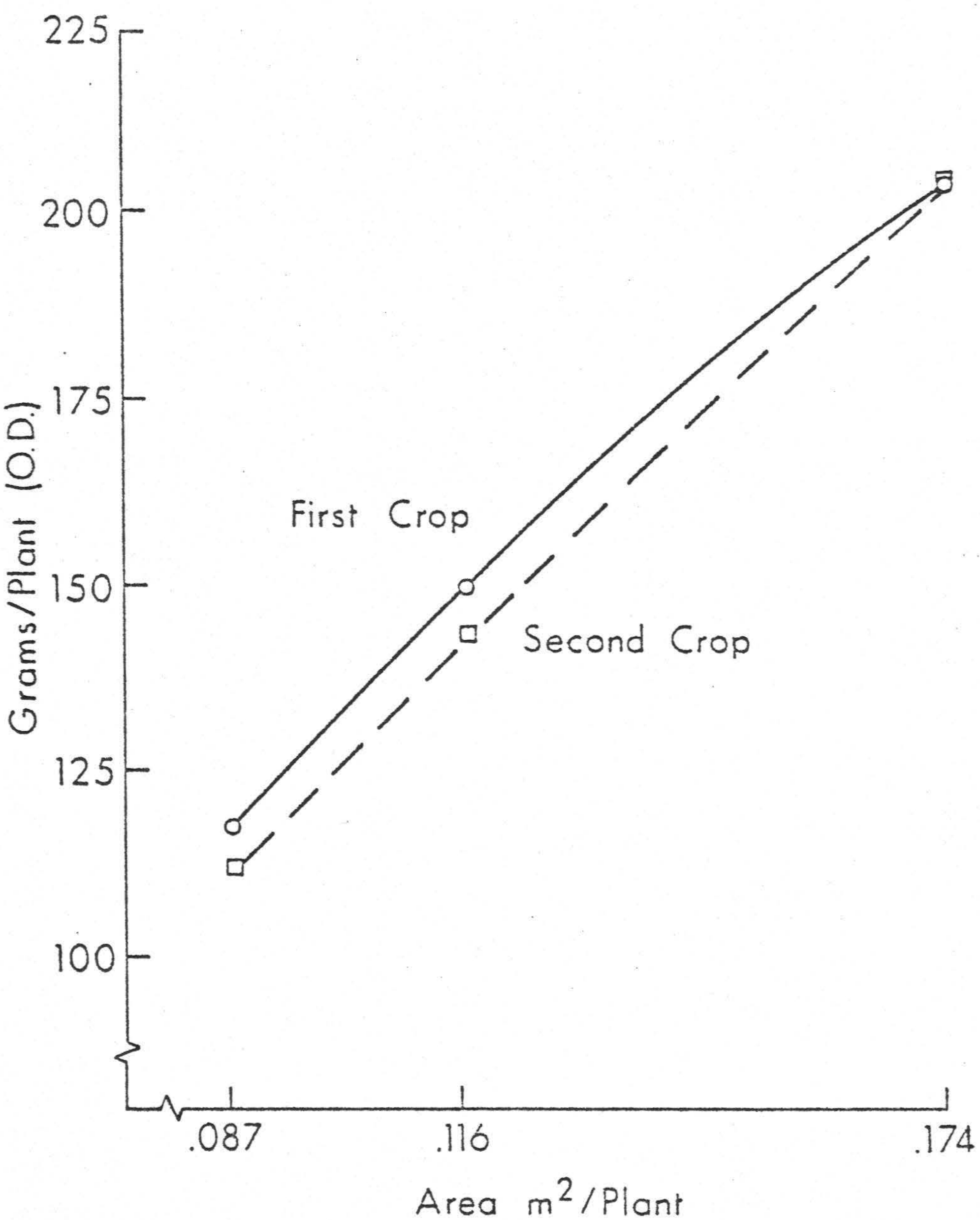

Fig. 1. The Effect of Area per Plant on Forage Yield at Kohala

plant were obtained for the 22.9 and 11.4 cm spacings respectively. It was also found that the two varieties did not differ significantly in dry matter production per plant (Table 7). Mean dry matter yield per plant for the two varieties were 157 g. All interactions of independent variables in this crop were not significant.

2. Second Crop

a. Forage Yield

The second crop was planted on the third of August 1977 and forage was harvested on 29th and 30th of November 1977. Nitrogen rates did not affect forage yield significantly (Table 5). Increasing plant density caused an increase in total forage production but the differences in yield were not significant (Table 6). As with the first crop, there were no significant differences due to variety or to the interactions between the dependent variables investigated (Table 7).

b. Dry Matter Yield Per Plant

Increasing rate of N applied failed to affect mean yield of dry matter/plant (Table 5), while increasing plant density consistently decreased dry matter production/plant (Table 6 and Fig. 1). The two varieties had comparable dry matter yield/plant, but H-688 was slightly higher than P-304B (Table 7).

B. Grain Yield and its Components

1. First Crop

a. Grain Yield

Significantly higher grain production was obtained when N rate was increased from 78.4 to 156.8 kg/ha (Table 5). As N rate was further increased to 313.6 kg/ha, yield was reduced (Table 5). The effect of plant density for the three populations investigated had no significant effect on grain yield (Table 6), while it was found that variety H-688 produced significantly higher yield (7.0 t/ha) than variety P-304B (6.3 t/ha), (Table 7).

b. Components of Grain Yield

The effect of N rate, plant spacing and variety on components of grain production namely: dry weight/ear, grain yield/plant, ratio of grain weight to whole plant weight (harvest index), and grain to ear ratio (shelling percent) were investigated. Nitrogen rate had slight but variable effects on these parameters. The differences between the treatment means failed to reach levels of significance (Table 5). On the other hand there were significant decreases in all of the above parameters with increasing plant density (Table 6). As for the two varieties, mean ear weight was similar, while grain yield/plant and grain to whole plant ratio were significantly higher for H-688 (Table 7). Variety P-304B was found to have significantly higher shelling percentage than H-699 (Table 7).

2. Second Crop

a. Grain Yield

Response of maize to N rates as manifested by grain yield of the second planting was strikingly similar to that of the first crop (Table 5 and Fig. 2). Yield increased significantly from 78.4 to 156.8 or 313.6 kg N/ha application with no significant differences between the last two rates (Table 5).

As plant density increased, grain yield dropped significantly from 6.9 to 6.6 and to 5.9 t/ha for 22.9, 15.4 and 11.4 cm spacings respectively (Table 6). For this time of planting, variety H-688 produced significantly more grain than P-304B (6.6 and 6.5 t/ha respectively). In this study,

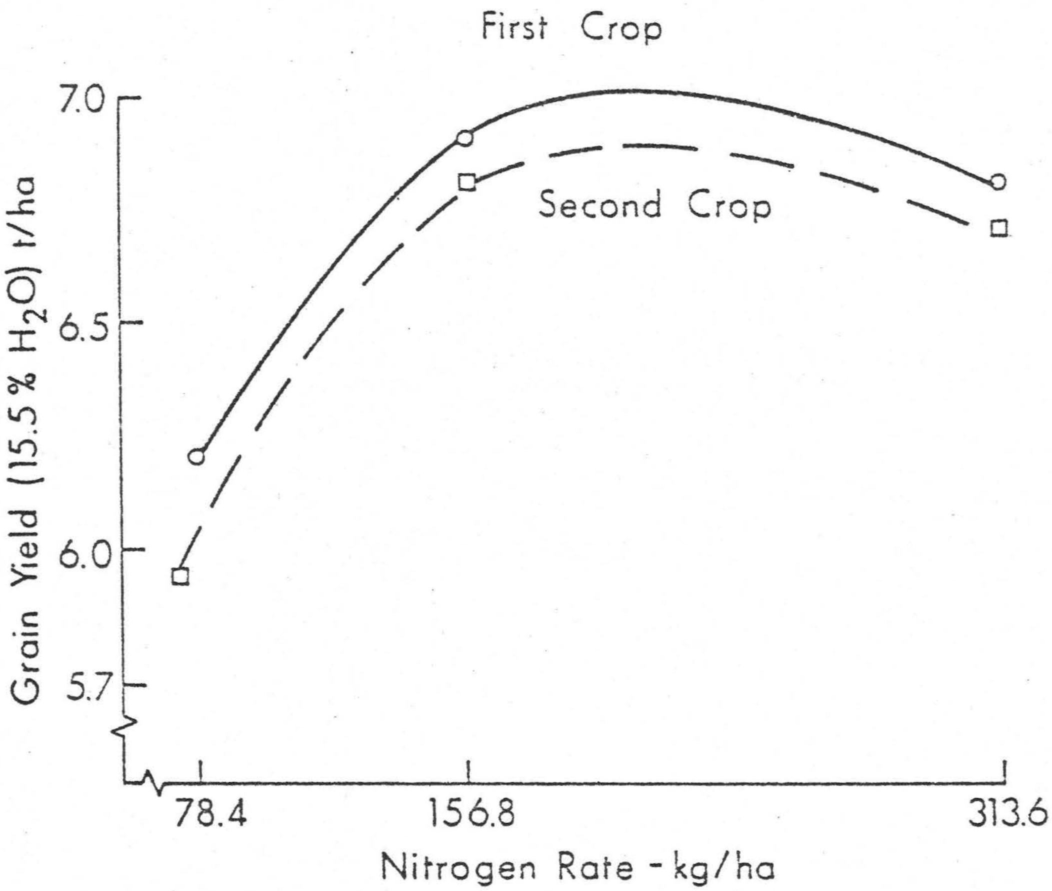

Fig. 2. The Effect of Nitrogen Fertilizer Rate on Grain Yield of Maize Grown in Two Seasons at Kohala

it is to be noted that there was a significant variety x rate of nitrogen interaction (Fig. 3). From this figure it is apparent that P-304B continued to respond to increasing N fertilizer rates while H-688 produced its highest yield at the 156.8 kg N/ha followed by a significant decrease in yield at the 313.6 kg N/ha application. Other interactions for these independent variables were not significant.

b. Components of Grain Yield

Ear weight and grain yield/plant increased significantly as N rate was raised from 78.4 to 156.8 or to 313.6 kg/ha (Table 5), but there was no significant difference between the two upper rates. Neither grain to whole plant ratio, nor grain to ear ratio were significantly affected by N rate (Table 5). With increasing plant population (Table 6), ear weight, grain yield per plant, grain to whole plant ratio and grain to ear ratio were found to decrease accordingly (Table 6). Variety H-688 had significantly higher grain yield per plant and lower shelling percentage than P-304B, but there were no significant differences for ear weight or grain to whole plant ratio between the two varieties (Table 7).

As would be expected, there was a significant variety x N rate interaction as expressed in grain yield per plant. These relationships are identical to those in Figure 3, which the only difference being the magnitude of yield. Other interactions were not significant.

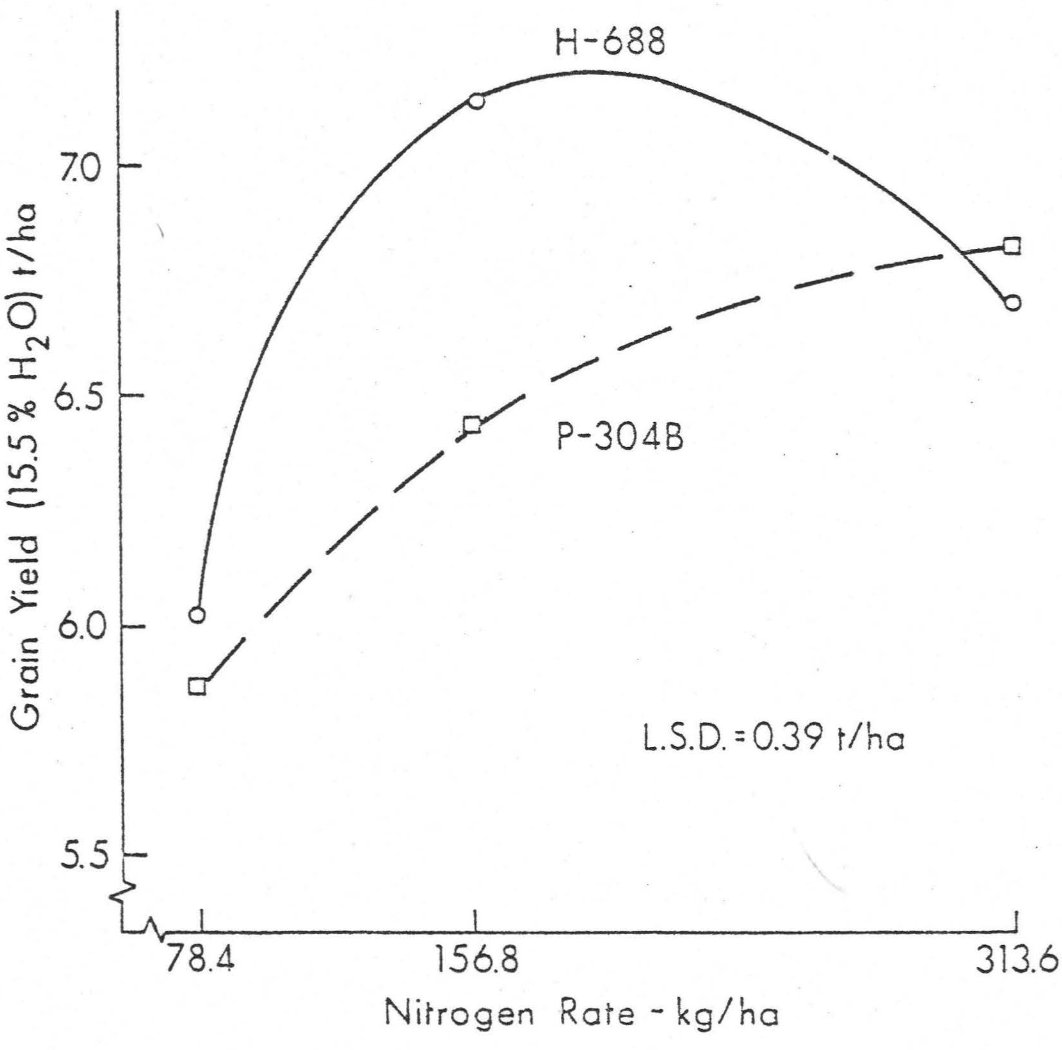

Fig. 3. The Effect of Nitrogen Fertilizer Rate and Variety on Grain Yield of Maize

II. THE EFFECT OF NITROGEN RATE AND PLANT SPACING ON MORPHOLOGICAL CHARACTERISTICS OF TWO MAIZE VARIETIES GROWN IN TWO SEASONS

Some of the morphological characteristics investigated were plant height, and stalk diameter for the first crop, and leaf weight, and ear production during the two planting seasons. In addition, data were also collected on lodging in the second crop.

A. Plant Height and Stalk Diameter

Investigating these two growth parameters during the first crop revealed that increasing N fertilizer rate significantly increased height and stalk diameter (Table 8). Growth stress due to increasing plant density caused a significant reduction in plant height and stalk diameter (Table 9). Variety H-688 was found to grow taller with thicker stalks than P-304B (Table 10).

B. Leaf Weight

Data on weights of ear-leaf which were collected when maize plants reached the early tasselling stage are reported in g/100 leaves. Leaf weight was found to increase with increasing rate of N in both crops (Table 8). The range in the first crop was 307-359 g/100 leaves (Fig. 4), while for the second crop it was 329-367 g/100 leaves. Leaf weight decreased drastically with decreasing area/plant (Fig. 5). For the first crop ear-leaf weight from plants spaced 22.9 cm was 384 g/100 leaves as compared to 299 g/100 leaves when plant spacing was reduced to 11.4 cm. With the same plant spacings during the second crop, mean weights/100 leaves were 406 and 309 g respectively. Leaf weight was similar for both varieties in the first crop, but variety P-304B with a mean of 359 g/100 leaves was significantly higher than H-688 with a mean of 347 g/100 leaves (Table 10).

Table 8: The effect of nitrogen fertilizer rate on growth parameters of maize grown at Kohala

N Rate kg/ha	Plant Height (m)	Plant Diameter (cm)	Weight Per 100 leaves (g)		Ears Per Plant		Plant Lodging (%)
	crop						
	1st	1st	1st	2nd	1st	2nd	2nd
78.4	1.87 c*	1.61 c	307 c	329 b	.92 a	.92 a	8.2 a
156.8	1.93 b	1.71 b	343 b	363 a	.94 a	.91 a	9.4 a
313.6	1.98 a	1.80 a	359 a	367 b	.92 a	.90 a	10.7 a

* Means in the same column followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 9: The effect of plant spacing on growth parameters of maize grown at Kohala

Plant Spacing (cm)	Plant Height (m)	Plant Diameter (cm)	Ears Per Plant		Plant Lodging (%)
	crop				
	1st	1st	1st	2nd	2nd
22.9	1.97 a*	1.93 a	.97 a	.97 a	6.4 b
15.4	1.94 a	1.67 b	.94 b	.92 b	9.4 b
11.4	1.86 b	1.52 c	.87 c	.84 c	12.4 a

* Means in the same column followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 10: Growth parameters of two maize varieties grown at Kohala

Variety	Plant Height (m)	Plant Diameter (cm)	Weight Per 100 Leaves (g)		Ears Per Plant		Plant Lodging (%)
	crop						
	1st	1st	1st	2nd	1st	2nd	2nd
H-688	1.95 a*	1.73 a	332 a	347 b	.94 a	.92 a	12.0 a
P-304 b	1.90 b	1.68 b	341 a	359 a	.92 b	.90 b	6.7 b

* Means in the same column followed by the same letter are not significantly different at P = .05 (Baye's least significant differences).

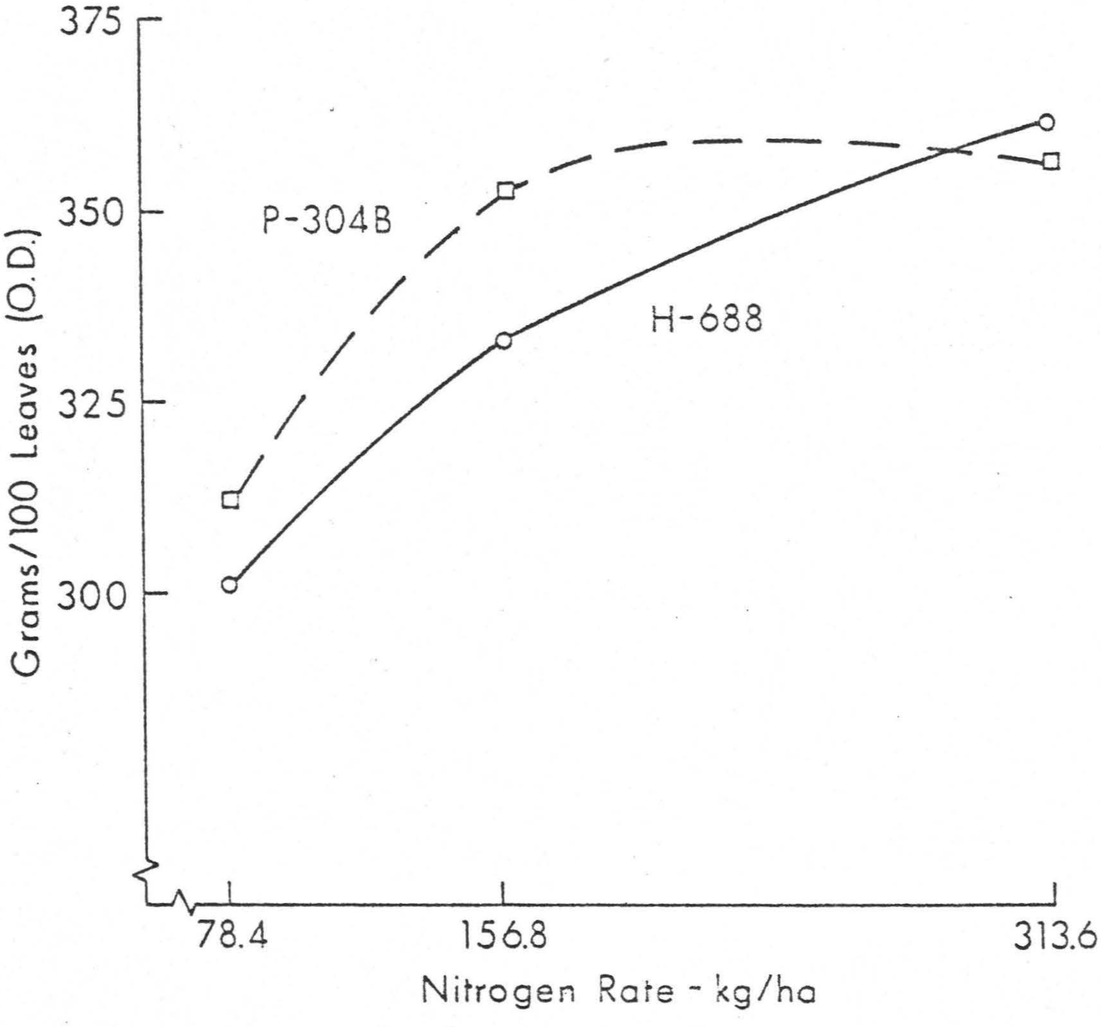

Fig. 4. The Effect of Nitrogen Rate of Ear-Leaf Weight of Two Maize Varieties Grown at Kohala

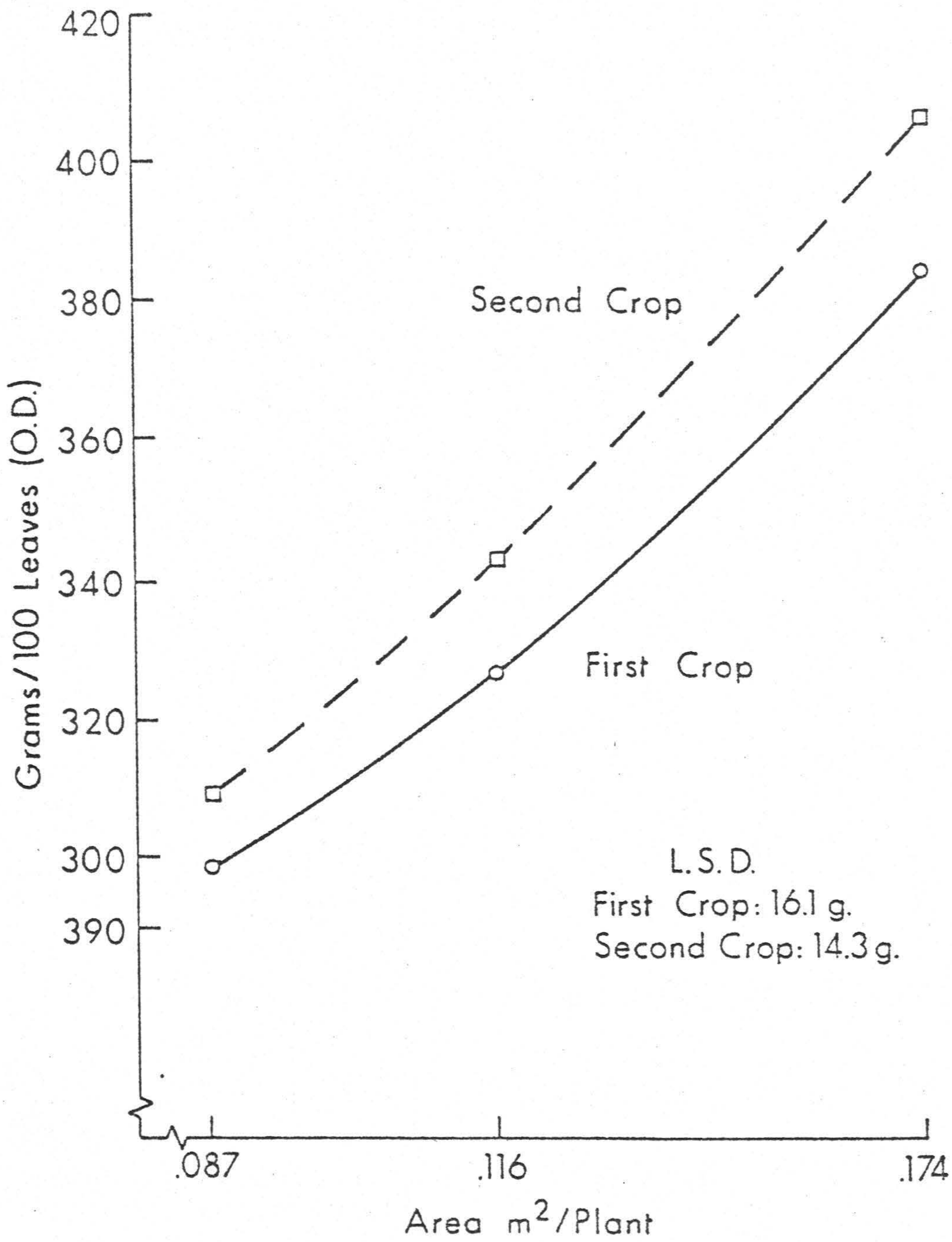

Fig. 5. The Effect of Nitrogen Fertilizer Rate on Ear Leaf Weight of Two Maize Varieties Grown at Kohala

C. Plant Lodging

Data on the effects of N rate and plant density on lodging for the two corn varieties was collected only for the second crop. Lodginging was slightly, but not significantly increased with increasing N rate (Table 8), while increasing plant population was found to significantly increase incidence of lodging as illustrated in Figure 6. It is also obvious from this figure that variety H-688 was more susceptible to lodging than P-304B.

D. Number of Ears Per Plant

The average number of ears/plant for the first and second crop did not vary significantly with N fertilizer rate (Table 8), but increasing plant density had a definite effect on reducing plant capability in setting ears as reported in Table 9. The highest figure was obtained at 22.9 cm spacing (97%) while the lowest ear setting occurred with the 11.4 cm spacing (85%). There was no significant difference between the two varieties for the first crop, while variety H-688 had significantly higher percent ear setting (92%) than variety P-304B (90%).

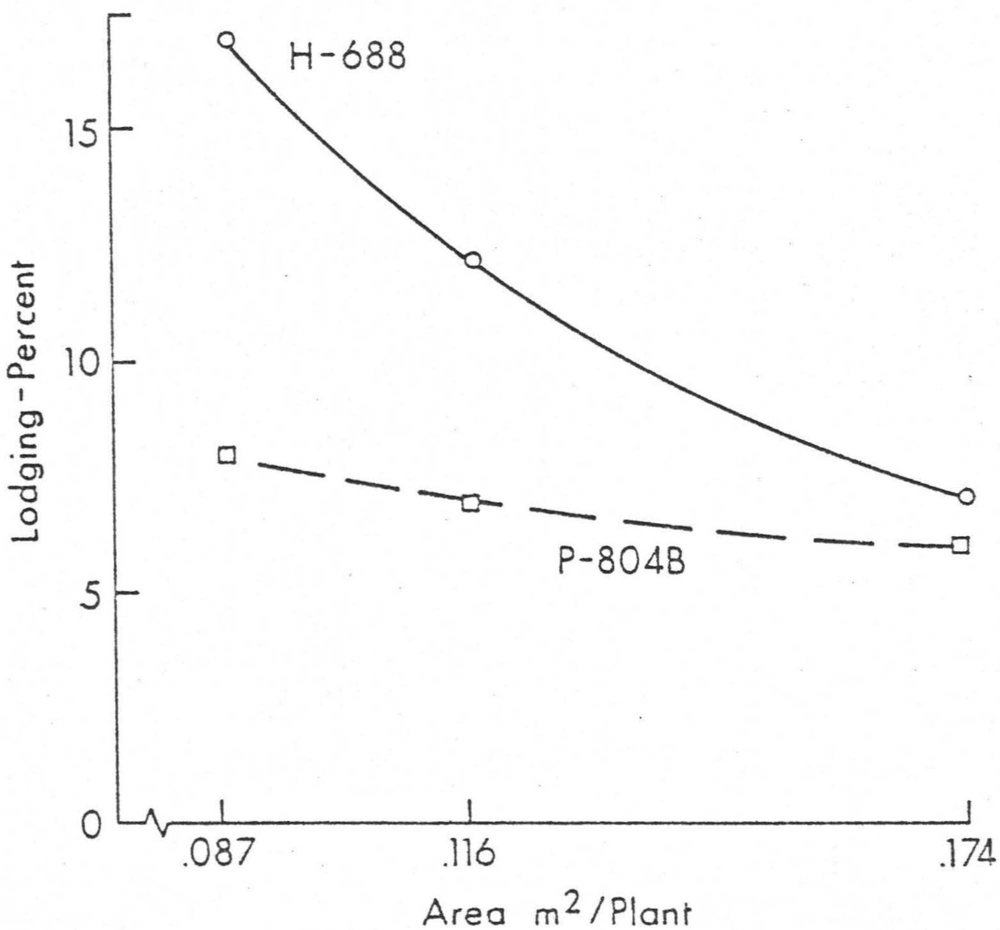

Fig. 6. The Effect or Plant Spacing on Lodging of Two Maize Varieties Grown at Kohala

III. THE EFFECT OF NITROGEN RATE, AND PLANT SPACING ON LEAF MINERAL CONTENT OF TWO MAIZE VARIETIES GROWN IN TWO SEASONS

A. Leaf Percent Dry Matter

1. First Crop

Percent dry matter in the ear leaf collected at early tasselling was found to be slightly higher in variety P-304B than in H-688 (Table 11). Meanwhile, levels of N fertilizer (Table 12) and plant spacing (Table 13) did not affect leaf dry matter content.

2. Second Crop

Dry matter percentage in the ear was not affected by N fertilizer rate (Table 12) but it was higher in plants with 15.4 cm spacing as compared to those grown at 22.9 cm spacing (Table 13). At the 11.4 cm spacing, leaves percent dry matter was not significantly different than in the above two spacings. Leaves collected from the two varieties had equal percent dry matter (Table 11). Leaves of variety P-304B were heavily infected with leaf rust (*Puccinia sorghi*) while leaves of H-688 were relatively free of rust.

B. Macro Elements

1. First Crop

a. Total Nitrogen

Leaf nitrogen was found to increase significantly when N fertilizer rate was raised from 78.4 to 156.8 or 313.6 kg N/ha (Table 12). Plants which received 78.4 kg N/ha were clearly chlorotic, a symptom of N deficiency. Differences in leaf N due to plant spacing or variety failed to reach levels of significance. Mean N level for this experiment was 2.52% N.

Table 11: Leaf dry matter and macro elements content of two maize varieties grown in two seasons at Kohala

Crop	Variety	D.M.	Leaf Level (%)						
			N	P	K	Ca	Mg	S	Si
First:									
	H-688	25.1 b*	2.51 a	.28 b	1.18 a	.42 a	.34 a	.15 a	1.76 b
	P-304B	25.6 a	2.52 a	.30 a	1.18 a	.36 b	.33 a	.16 a	1.49 b
Second:									
	H-688	24.0 a	2.51 a	.29 a	1.43 a	.40 a	.33 a	.16 a	1.49 b
	P-304B	24.0 a	2.50 a	.30 a	1.31 b	.39 a	.30 b	.14 b	1.65 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 12: The effect of nitrogen rate on dry matter and the levels of macroelements in maize leaves for two growing seasons at Kohala

Crop	N Rate kg/ha	Leaf Level (%)							
		D.M.	N	P	K	Ca	Mg	S	Si
First:									
	78.4	25.2 a*	2.38 b	.28 c	1.14 b	.39 a	.31 a	.13 a	1.86 a
	156.8	25.3 a	2.58 a	.29 b	1.20 a	.39 a	.30 a	.14 b	1.86 a
	313.6	25.5 a	2,59 a	.30 a	1.19 a	.40 a	.31 a	.15 a	1.73 a
Second:									
	78.4	24.3 a	2.23 c	.28 b	1.30 c	.37 c	.30 b	.13 c	1.64 a
	156.8	23.9 a	2.57 b	.30 a	1.38 b	.40 b	.32 a	.15 b	1.63 a
	313.6	23.9 a	2.71 a	.30 a	1.43 a	.41 a	.33 a	.16 a	1.44 b

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 13: The effect of plant spacing on maize leaf dry matter and macro elements content for two growing seasons at Kohala

Crop	Spacing (cm)	Leaf Level (%)							
		D.M.	N	P	K	Ca	Mg	S	Si
First:									
	22.9	25.2 a*	2.50 a	.30 a	1.21 a	.40 a	.31 a	.15 a	1.82 a
	15.4	25.3 a	2.55 a	.29 b	1.18 ab	.39 a	.31 a	.14 b	1.86 a
	11.4	25.2 a	2.49 a	.28 c	1.15 b	.38 a	.31 a	.14 b	1.78 a
Second:									
	22.9	23.7 b	2.57 a	.30 a	1.40 a	.41 a	.33 a	.15 a	1.66 a
	15.4	24.3 a	2.48 b	.30 a	1.37 a	.38 b	.30 a	.14 b	1.54 a
	11.4	24.0 ab	2.46 b	.29 b	1.35 a	.38 b	.31 a	.14 b	1.51 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant differences).

b. Phosphorus

Increasing levels of N fertilizer caused increases in leaf P (Table 12) but the level of this element was found to decrease significantly with increasing plant population (Table 13). Variety P-304B had a mean P level of 0.30% which was significantly higher than the 0.28% P in leaves of H-688 (Table 11).

c. Potassium

Concentration of K in maize leaves was found to increase from 1.14 to 1.20% with applications of 78.4 and 156.8 kg N/ha respectively, with no significant increase at 313.6 kg N/ha (Table 12). As plant density increased, leaf percent K decreased (Table 13). Leaves of the two varieties tested had an equal concentration of K (1.18%, Table 11).

d. Calcium and Magnesium

Nitrogen fertilizer rate and plant spacing had no significant effects on leaf Ca or Mg. Leaves of the two varieties were found to have significantly different levels of these elements. Leaf Ca and Mg in variety H-688 were 0.42% and 0.34% as compared to 0.36% and 0.27% for P-304B respectively (Table 11).

e. Sulfur

Incremental increases of N fertilization caused a continuous increase in leaf S (Table 12). The highest level of 0.15% S was found in leaves where plants received 313.6 kg N/ha. As plant spacing was decreased from 22.9 to 15.4 or 11.4 cm, leaf percent S decreased from 0.15 to 0.14% (Table 13). Leaves of maize variety H-688 accumulated higher levels of S, 0.15%, as compared to 0.13% for variety P-304B (Table 11).

f. Silicon

Neither level of N fertilization nor plant density had any significant increase on leaf Si level while variety P-304B, with 1.88% Si, was significantly higher than 1.78% Si for variety H-688.

2. Second Crop

a. Total Nitrogen

With 78.4 kg N/ha treatment, leaves had 2.23% total N as compared to 2.57% and 2.71% N for doubling and quadrupling the N rate applied (Table 12). In this crop, leaf nitrogen was highest in leaves of plants spaced at 22.9 cm with an average of 2.57% N (Table 13). As plant population increased, leaf N% was found to decrease. The two varieties were found to accumulate similar levels of N in their ear leaf (Table 11).

b. Phosphorus

Leaf phosphorus in the second crop was increased from 0.28 to 0.30% by doubling the N rate of 78.4 kg/ha, while at the highest N rate, it remained constant (Table 12). Plant spacing affected the level of this element only when it was 11.4 cm between plants by lowering it from 0.30 to 0.29% (Table 13), while the two varieties did not differ significantly (Table 11).

c. Potassium

Potassium concentration in leaves was progressively increased with increasing N fertilizer rate (Table 12), but concentration of this element declined slightly as plant density was increased (Table 13). Variety H-688 accumulated significantly more K in its leaves than variety P-304B (Table 11).

d. Calcium and Magnesium

Doubling or quadruping N fertilizer rate of 78.4 kg/ha was found to cause continuous increase in leaf Ca (Table 12). This element retained the same concentration (0.38%) at the highest and medium density, while at the lowest plant density its level was significantly increased (0.41%, Table 13). Level of this element in the two varieties did not differ significantly. Leaf Mg percent was higher in plants which received 156.8 or 313.6 kg N/ha than those which received 78.4 kg N/ha (Table 12). Plant spacing did not have any significant affect on this element. Mg in the leaves of variety H-688 was 0.33%, which is significantly higher than 0.30% Mg found in leaves of variety P-304B.

e. Sulfur

Leaf sulfur content was significantly affected by the three independent variables investigated. Its level in leaves increased with increasing N fertilizer rate (Table 12). The highest level with the population variable was found where plants were spaced 22.9 cm, 0.15% S, as compared to 0.14% for the other two spacings (Table 13). Leaves of variety H-688 were higher in this element than in P-304B (Table 11).

Significant N rate x spacing interaction on the concentration of S in corn leaves is illustrated in Figure 7. At low level of N fertilizer (78.4 kg/ha) tissue S was found to increase with increasing space between plants. At the medium level of 156.8 kg N/ha, leaf S was not significantly affected by plant spacing, but it was consistently higher than that of the lower N rate at corresponding plant density. At the highest rate of 313.6 kg N/ha, leaf S was not different in the high and medium plant density, but increased significantly at largest area per plant spacing (22.9 cm).

f. Silicon

Level of silicon in leaves dropped significantly when N rate was raised to 313.6 kg/ha as compared to either 78.4 or 156.8 kg/ha treat-

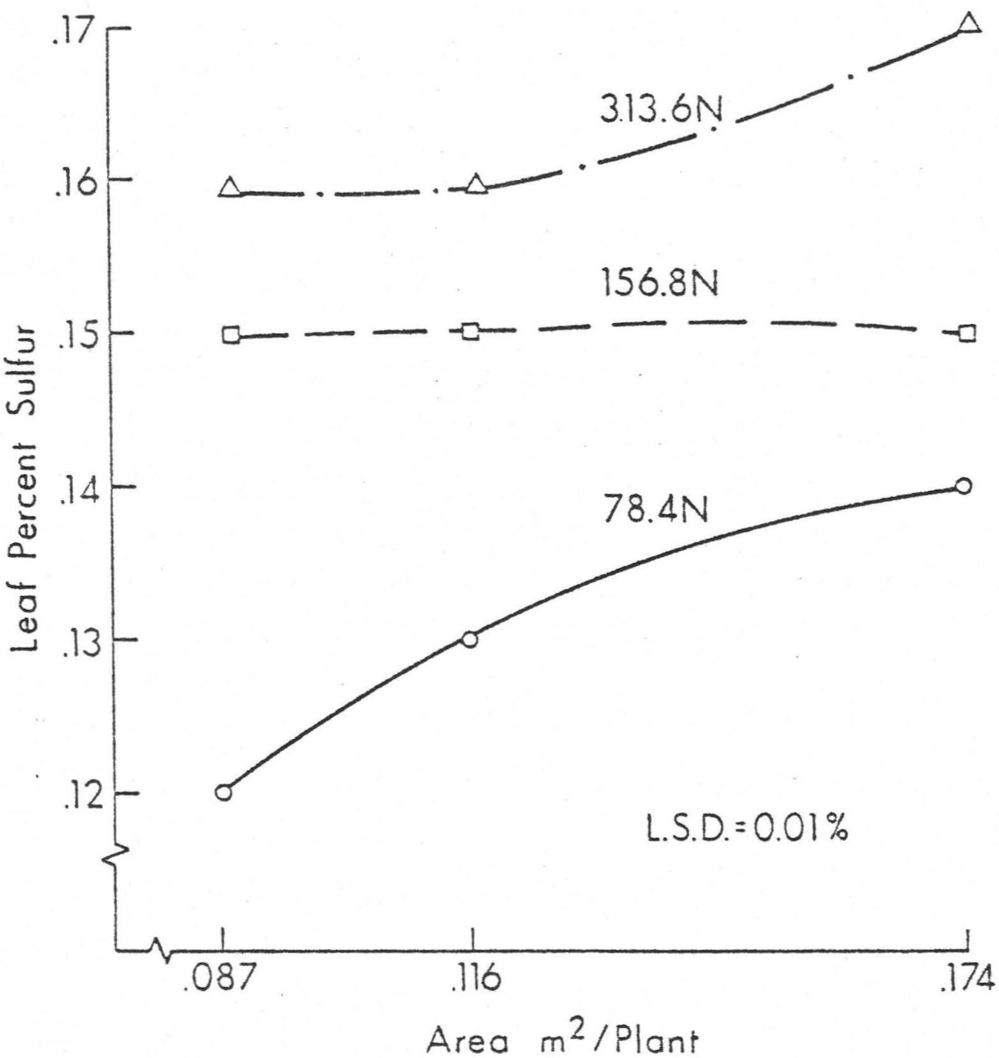

Fig. 7. The Effect of Plant Spacing and Nitrogen Fertilizer Rate on Ear Leaf Sulfur

ments (Table 12). Plant spacing did not affect this element while variety H-688 had significantly lower Si level than P-304B (Table 11). Mean Si for the whole experiment was 1.57%.

C. Micronutrients

1. First Crop

a. Zinc

Leaf Zn was found to increase when N fertilizer rate and spacing between plants were increased (Tables 14 and 15), but with no significant difference between the two varieties (Table 16).

With increasing N rate leaf levels of Zn were : 20.3, 22.4, 23.6 ppm, for 78.4, 156.8, 313.6 kg N/ha applications respectively. Levels of 23.8, 21.9 and 20.6 ppm, Zn were associated with plant spacings of 22.9, 15.4 and 11.4 cm respectively.

b. Copper

Copper leaf content increased with increasing nitrogen rate and decreased with closer planting density (Tables 14 and 15). Variety H-688 with an average of 8.1 ppm Cu was significantly higher than variety P-304B which had an average of 7.5 ppm Cu. The interaction between N rate x variety was statistically significant as illustrated in Figure 8. With variety H-688, leaf Cu content increased with increasing N rate applied through the range, while with variety P-304B. Cu level increased due to the second increment of N over the first and slightly dropped at the highest rate of N. The range of leaf Cu content was 6.25 to 9.0 ppm.

c. Manganese

Leaf Mn level was influenced only by variety. For this crop leaves of variety H-688 had significantly higher Mn level, 33.1 ppm, as compared

Table 14: The effect of nitrogen rate on the levels of some micro nutrients in maize leaves for two growing seasons at Kohala

Crop	N Rate kg/ha	Element Level (ppm)			
		Zn	Cu	Mn	Fe
First	78.4	20.3 b*	6.9 b	29.5 a	160 b
	156.8	22.4 a	8.0 a	30.7 a	185 a
	313.6	23.6 a	8.1 a	33.7 a	172 ab
Second:					
	78.4	26.6 c	8.3 c	44.1 a	178 a
	156.8	30.0 b	9.6 b	43.7 a	189 a
	313.6	34.7 a	11.5 a	45.8 a	176 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 15: The effect of plant spacing on levels of some micronutrients in leaves of maize for two growing seasons at Kohala

Crop	Spacing (cm)	Element level (ppm)			
		Zn	Cu	Mn	Fe
First:					
	22.9	23.8 a*	8.3 a	29.9 a	173 a
	15.4	21.9 b	7.8 ab	32.5 a	165 a
	11.4	20.6 c	7.3 b	31.5 a	179 a
Second:					
	22.9	31.7 a	10.0 a	45.3 a	180 a
	15.4	30.3 ab	9.9 a	44.4 a	179 a
	11.4	29.3 b	9.5 a	43.9 a	182 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 16: Leaf micronutrients content of two maize varieties in two growing seasons at Kohala

		Element Level (ppm)			
Crop	Variety	Zn	Cu	Mn	Fe
First:					
	H-688	21.9 a*	8.1 a	33.1 a	175 a
	P-304B	22.3 a	7.5 b	29.4 b	170 a
Second:					
	H-688	29.7 a	10.4 a	43.4 b	186 a
	P-304B	31.1 a	9.3 b	45.6 a	175 b

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

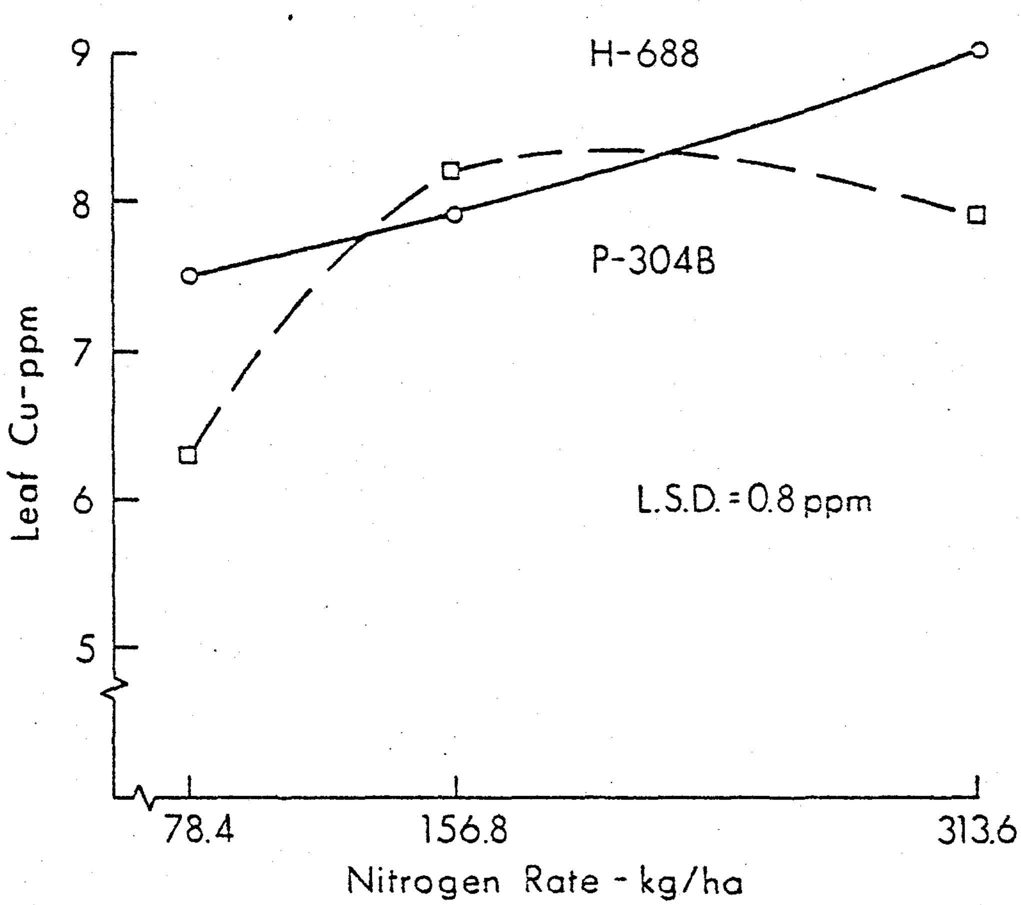

Fig. 8. The Effect of Nitrogen Fertilizer Rate and Maize Variety on Ear Leaf Copper Content

to P-304B with 29.4 ppm (Table 16).

d. Iron

Iron concentration in maize leaves increased with the second increment of N, and decreased slightly at the highest N rate (Table 14). Levels of 160, 185 and 172 ppm Fe in leaves were found when 78.4, 15.8 and 313.6 kg N/ha were applied. There were no significant differences that could be attributed to plant spacing or to variety (Tables 15 and 16).

2. Second Crop

a. Zinc

Leaf content of Zn increased significantly with increasing N fertilizer rate (Table 14). The highest level obtained was 34.7 ppm when 313.6 kg N/ha were applied. Similar to the first crop, increasing plant density caused a decline in the level of this element (Table 15), while its level in the leaves of the two varieties did not differ significantly (Table 16).

b. Copper

There were differences in leaf Cu levels due to N fertilizer rate and variety, but plant spacing did not affect this element significantly. Its level increased significantly with increasing N fertilizer rate (Table 14) and variety H-688 had higher level (10.4 ppm) than variety P-304B (9.3 ppm, Table 16).

c. Manganese

Manganese level in maize leaves was significantly higher in variety P-304B (45.6 ppm) than in variety H-688 (43.4 ppm, Table 16). Neither N-rate nor plant density had any significant effect on this element (Table 14 and 15).

d. <u>Iron</u>

Nitrogen rate and plant density did not have a significant effect on Fe, while variety H-688, with 186 ppm Fe, was significantly higher than variety P-304B, with 175 ppm, (Table 16).

IV. EFFECT OF NITROGEN RATE AND PLANT SPACING ON FORAGE QUALITY COMPONENTS OF TWO MAIZE VARIETIES GROWN IN TWO SEASONS

A. Dry Matter

1. First Crop

The effect of increasing rates of N fertilizer on forage percent dry matter was not significant. Mean percent dry matter for the experiment was 42.0%. Forage percent dry matter increased significantly from 40.5 to 42.3% when plant density was increased from 57,406 to 86,109 plants/ha (Table 17). Further increase in plant density, (114,813 plants/ha) resulted in a very small net increase in dry matter percentage. The two varieties differed significantly, where H-688 had an average dry matter of 44.1% as compared to 39.8% for variety P-304B (Table 18). Variety H-688 tended to mature earlier than P-304B.

2. Second Crop

The effect of N fertilizer level of % dry matter in whole plant maize was significant (Table 19). Dry matter percent was found to decrease as N rate was increased. Plant spacing in this crop failed to affect dry matter content while variety H-688 which is earlier to mature, had significantly higher percent dry matter than P-304B (Table 18).

B. Macro-elements

1. First Crop

a. Total Nitrogen

Increasing nitrogen fertilizer rate significantly enhanced its total uptake by maize plants. At 78.4 kg N/ha, the forage had 0.91% total N, which increased to 0.99 and 1.08% with increasing N fertilizer rate (Table 19). The interaction effect of N rate x spacing affected forage total nitrogen significantly (Figure 9). Response to increasing N rate

Table 17: The effect of plant spacing on maize forage dry matter and macro elements content for two growing seasons at Kohala

Crop	Spacing (cm)	Forage Level (%)							
		D.M.	N	P	K	Ca	Mg	S	Si
First:									
	22.9	40.5 b*	1.00 a	.21 a	.58 a	.12 a	.18 a	.06 a	.67 a
	15.4	42.3 a	0.97 a	.21 a	.54 b	.12 a	.17 b	.05 b	.70 a
	11.4	43.0 a	1.00 a	.21 a	.52 b	.12 a	.18 a	.05 b	.68 a
Second:									
	22.9	50.9 a	1.07 a	.20 a	.66 a	.14 a	.21 a	.07 a	.67 a
	15.4	52.8 a	1.10 a	.22 a	.69 a	.13 a	.21 a	.07 a	.64 a
	11.4	53.1 a	1.08 a	.21 a	.60 b	.13 b	.21 a	.07 a	.64 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 18: Forage dry matter and macro elements content of two maize varieties grown in two seasons at Kohala

		Forage Level (%)							
Crop	Variety	D.M.	N	P	K	Ca	Mg	S	Si
First:									
	H-688	44.1 a*	0.96 a	.20 a	.53 b	.12 b	.18 a	.06 a	.62 b
	P-304B	39.8 b	1.01a	.21 a	.57 a	.13 a	.18 a	.05 b	.74 a
Second:									
	H-688	55.9 a	1.11 a	.22 a	.65 a	.13 b	.21 a	.07 a	.59 b
	P-304B	48.6 b	1.05 b	.21 a	.65 a	.14 a	.21 a	.06 b	.71 a

* Means in the same column under each crop followed by the same le ter are not significantly different at P = .05 (Baye's least significant difference).

Table 19: The effect of nitrogen rate on dry matter and the levels of micro elements in maize forage for two growing seasons at Kohala

Crop	N Rate kg/ha	Forage Level (%)							
		D.M.	N	P	K	Ca	Mg	S	Si
First:									
	78.4	41.4 a*	0.91 c	.21 a	.53 b	.12 a	.18 a	.05 b	.76 a
	156.8	42.2 a	0.99 b	.21 a	.54 b	.12 a	.17 a	.06 a	.67 b
	313.6	42.2 a	1.08 a	.21 a	.58 a	.12 a	.18 a	.06 a	.62 b
Second:									
	78.4	54.9 a	0.93 c	.22 a	.63 a	.12 b	.19 c	.05 c	.69 a
	156.8	52.1 ab	1.12 b	.21 a	.63 a	.14 a	.20 b	.06 b	.66 a
	313.6	49.7 b	1.20 a	.20 a	.69 a	.14 a	.23 a	.07 a	.59 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

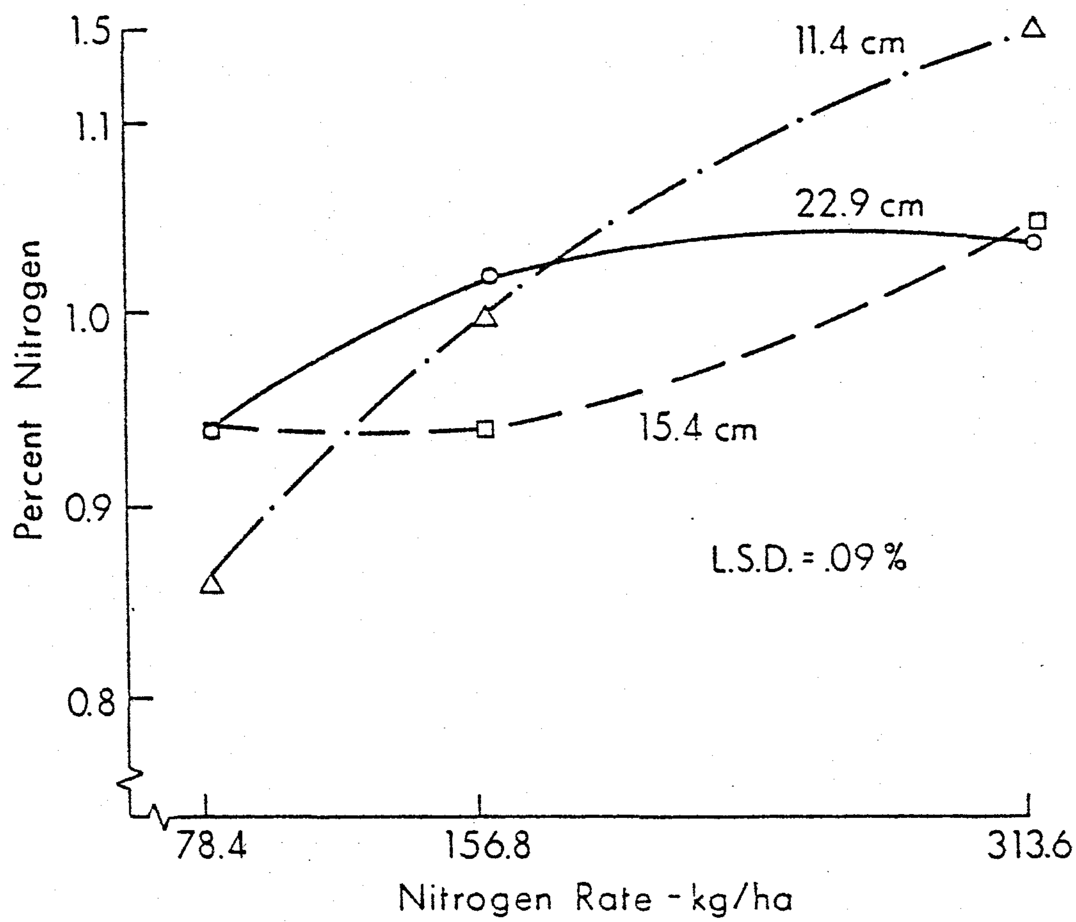

Fig. 9. The Effect of Nitrogen Fertilizer Rate on Forage Maize Total Nitrogen Crown in Two Seasons

with the highest plant density (11.4 cm spacing), was continuous, while within the medium density, forage nitrogen increased only when N rate was 313.6 kg/ha. At the lowest plant density (22.9 cm spacing), forage N percent increased with the medium N fertilizer level and nearly remained the same at the highest N rate of fertilizer (Figure 9).

Variety P-304B had relatively higher percent total N than that of H-688, but this difference was not significant. It is worth noting that this difference may be due in part to the earlier maturity of variety H-688.

b. Phosphorus

Plant phosphorus remained relatively constant regardless of N rate, plant spacing, or variety. The mean tissue content was 0.20 and 0.21% for varieties H-688 and P-304B respectively.

c. Potassium

Tissue percent K was found to increase slightly when N rate was raised from 78.4 to 156.8 kg/ha (Table 19). Application of 313.6 kg N/ha was found to significantly increase forage percent K. Potassium level in the plant decreased when plant spacing was decreased. At spacings of 22.9, 15.4 and 11.4 cm, plant K was 0.58, 0.54 and 0.52% respectively, with variety H-688 being significantly lower than P-304B (0.53 and 0.57% K respectively, Tables 17 and 18).

d. Calcium and Magnesium

Calcium level in whole plant maize was not significantly affected by N rate of plant spacing (Table 17 and 19). Variety H-688 was significantly higher in this element than P-304B (Table 18). Plants were higher in Mg when spaced 22.9 or 11.4 cm than at 15.4 cm (Table 17). Neither N rates nor variety had a significant effect on tissue Mg (Tables 18 and 19).

e. Sulfur

There was an increase in plant S as rate of N fertilizer was increased (Table 19). The highest concentration was 0.06% for the 313.6 kg N/ha as compared to 0.05% when 78.4 kg N/ha were applied. Increasing plant population caused a decrease in tissue S (Table 17) while variety H-688 had significantly higher level of this element than P-304 B (Table 18).

f. Silicon

Silicon level in the forage was affected significantly by N rate and variety but not by plant spacing (Table 18 and 19). A significant decline from 0.76 to 0.67% Si was obtained as N rate was increased from 78.4 to 156.8 kg/ha. Further decline in percent Si at 313.6 kg N/ha was not significant. Variety P-304B was found to have a higher Si level than H-688 (Table 18).

2. Second Crop

a. Total Nitrogen

Increasing fertilizer N rate consistently increased tissue N as illustrated in Table 19. The highest level of 1.20% N was obtained with 313.6 kg N/ha as compared to 0.93% N for plants which received 78.4 kg N/ha. Plant spacing had no significant effect on total N (Table 17), while variety H-688 had significantly higher level of total N than P-304B (Table 18).

b. Phosphorus

Plant phosphorus was found to be independent of N rates, plant density or variety. Mean tissue phosphorus for the whole experiment was 0.21% P.

c. Potassium

Plant K was found to increase slightly at the medium population density while tissue level of this element was reduced slightly when plant spacing was decreased to 11.4 cm (Table 17). Neither N fertilizer level nor variety showed any significant effect of plant K level (Tables 18 and 19).

d. Calcium and Magnesium

Tissue Ca level was not significantly affected by plant spacing (Table 17). Increasing N rate from 78.4 to 156.8 or 313.6 kg/ha raised the Ca level from 0.12 to 0.14% respectively (Table 19). Maize variety P-304B was significantly higher in Ca than H-688, 0.14 vs 0.13% respectively. Plant Mg in this season was found to increase with increasing N rate (Table 19), while variety and spacing had no significant effects (Table 17 and 18).

e. Sulfur

Similar to the first crop, plant sulfur increased with increasing rate of N fertilizer (Table 19), while plant density had no significant effect on tissue S. As per variety, H-688 was found to have significantly higher level of S (0.07%) than P-304B (0.06%).

f. Silicon

With all three variables and their interactions, only variety showed any difference in tissue Si content. P-304B with 0.71% Si was significantly higher than H-688 which had 0.59% Si.

C. Micronutrients

1. First Crop

Neither N rate nor plant spacing were found to have any significant effect on plant Zn level, while variety H-688 had a slightly lower concentration (17.6 ppm), than P-304B (18.3 ppm).

Copper uptake was slightly enhanced with increasing N fertilizer (Table 20), but was not affected by either spacing or variety. Mean Cu concentration in the forage was 2.4 ppm. Level of Mn in the tissue was increased with increasing population but was not affected by nitrogen fertilizer rate while variety P-304B had significantly higher level (47.0 ppm) than H-688 (40.3 ppm). Plant iron was found to be affected only by plant density (Table 21). There was no difference between the level in medium and low density population, while with the highest density iron level increased by over 100 ppm (Table 21).

2. <u>Second Crop</u>

Plant levels of Cu and Mn were enhanced with higher rates of N fertilizer (Table 20), while plant spacing had no significant effect on levels of micronutrients tested. Maize hybrid H-688 contained slightly higher levels of Zn and Cu than P-304B (Table 22), while concentration of other micronutrient elements were not significantly different in the two varieties.

Mean Fe level in this experiment was 444 ppm.

Table 20: The effect of nitrogen rate on the levels of some micronutrients in maize forage for two growing seasons at Kohala

Crop	N Rate kg/ha	Element level (ppm)			
		Zn	Cu	Mn	Fe
First:					
	78.4	17.5 a*	2.0 b	42 a	711 a
	156.8	17.6 a	2.4 b	42 a	666 a
	313.6	18.7 a	2.9 a	47 a	621 a
Second:					
	78.4	27.7 a	4.1 b	43 b	458 a
	156.8	29.2 a	4.5 b	45 ab	458 a
	313.6	29.8 a	5.2 a	49 a	415 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = .05 (Baye's least significant difference).

Table 21: The effect of plant spacing on levels of some micronutrients in forage of maize for two growing seasons at Kohala

Crop	Spacing (cm)	Element Level (ppm)			
		Zn	Cu	Mn	Fe
First:					
	22.9	18.1 a*	2.8 a	41.6 b	630 b
	15.4	17.8 a	2.2 b	43.0 b	632 b
	11.4	17.8 a	2.3 a	46.3 a	736 a
Second:					
	22.9	27.9 a	4.8 a	46.0 a	457 a
	15.4	29.5 a	4.8 a	46.0 a	454 a
	11.4	29.3 a	4.3 a	45.0 a	420 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = 0,05 (Baye's least significant difference).

Table 22: Forage micronutrients content of two maize varieties in two seasons at Kohala

		Element Level (ppm)			
Crop	Variety	Zn	Cu	Mn	Fe
First:					
	H-688	17.6 a*	2.4 a	40.3 b	644 a
	P-304B	18.3 a	2.4 a	47.0 a	688 a
Second:					
	H-688	30.5 a	4.9 a	43.8 a	457 a
	P-304B	27.3 b	4.3 b	47.2 a	431 a

* Means in the same column under each crop followed by the same letter are not significantly different at P = 0.05 (Baye's least significant difference).

DISCUSSION

Yield and its components

Forage

Two maize varieties grown in two different seasons at Kohala had a range of forage production from as low as 11.5 to as high as 13.0 t/ha depending upon N fertilizer rate, plant population density and variety. Highest yield was obtained at N rates of 156.8 or 313.6 kg/ha as compared to an application of 78.4 kg/ha. Yield response to N fertilization was curvilinear, indicating that approximately 200 kg/ha of N may produce maximum yield. Several workers, Doss et al (1970), Gonske et al (1969), Mason et al (1974) and Henshaw et al (1976), obtained results similar to those reported here. N rate of 313.6 kg/ha seemed to be excessive, while 78.4 kg/ha was inadequate for maximum production. Excess nitrogen would be expected to result in production of toxic substances from breakdown of proteins under heavy mutual shading, thus reducing yield.

Forage yield increased with increasing plant population, but this effect was significant only for the first crop and when population was increased from 57,406 to 86,109 or 114,813 plants per hectare. These trends are similar to results obtained in England by Bunting (1971) and Phipps (1975) who recommended 10-15 and 11-16.7 plants/m^2, respectively, for maximum forage production. Similar trends were reported in North America. Rutger and Crowder (1967) reported that maximum yield was obtained with 32,000 plants per acre which was not significantly different than the yield obtained from 28,000 plants per acre. Increase in forage yield per unit area could be attributed in part to more plants per unit area. Increasing plant density is also known to increase the leaf area indices (LAI), thus increasing the efficiency of light interception which favor higher forage production (Duncan 1969).

It is to be noted that the first crop which was planted in March produced higher yields than the second crop which was planted in early August. This could be due to longer days and possibly higher solar radiation during the first growing season. This is in agreement with reports from Hawaii by Villanueva (1971) and Tamimi et al (1977).

Individual plant weight was severely reduced with increasing population density. Yield per plant at 11.4 cm spacing was reduced to nearly 1/2 that of the 22.9 cm spacing in both seasons. These reductions may be due to competition for light, leading to poor root development thus, less nutrient uptake required for optimum growth of each plant.

Grain

Application of 78.4 kg N/ha was found to be inadequate for maximum grain production by the two tropical varieties tested. The yield was significantly increased when 156.8 or 313.6 kg N/ha were applied; but there was no significant difference between these two treatments. Similar results have been reported by Lang et al (1956), Numez and Kamprath (1969) and Nelson and Mac Gregor (1973). Meanwhile a parallel response to N rates was obtained for the two seasons showing that its effect was independent of season (Figure 2). Results obtained here indicate that 200 kg N/ha seem to produce optimum grain yield. This N rate is within the range at which recommendations have been made in Hawaii (Brewbaker, 1976; Fox, 1973; Tamimi et al, 1976).

The effect of plant spacing on grain yield was different in the two growing seasons. For the first crop, grain yield was optimum at 17.8 cm whereas maximum yield was obtained at 22.9 cm spacing in the second crop.

During the latter season and as plant population increased, grain yield continued to decrease significantly. These observations show that population stress had more effect in the second crop than in the first. Murata (1969) suggested that high levels of nitrogen fertilization, when accompanied by low light intensity may have accentuated the photosynthesis-respiration imbalance. This may cause a reduction in carbohydrate accumulation which adversely affects grain filling. Results of the first crop are in agreement with the commonly held view that grain yields are relatively insensitive to plant density according to Robertson et al (1968) and Robinson and Murphy (1972). Due to the remarkable compensatory power of cereals, Donald (1963) also noted that reducing the seed rate by half rarely alters yield because plant at low density approach their maximum yield potential. Williams et al (1968) remarked that LAI increase with increasing light, temperature, fertilization and sowing density. They maintain that yield tend to increase with increasing LAI until a plateau is reached, beyond which yield of grain falls.

In this experiment variety H-688 outyielded variety P-304B consistently in both seasons by 700 kg and 200 kg/ha respectively. This could be attributed to its genetical superiority as well as to better resistance to leaf rust.

Ear weight was more affected by area per plant than by variety or nitrogen levels which is in agreement with the findings of Land et al (1956). Increasing N rate was found to significantly increase ear weight only for the second crop. In both seasons, decreasing area per plant caused a highly significant decline in ear weight. Decreases in the ear-weight at the high stand density may be due to the keen competition between plants for light interception during the process of ear development.

Similar relationships of ear size to varying density have been reported by Bunting (1973) and Phipps (1975).

Nitrogen levels did not significantly affect grain yield per plant of the first crop, while in the second crop the effect was significant. Application of 156.8 or 313.6 kg N/ha produced significantly higher yield per plant than 78.4 kg/ha. Moreover, the N rate x variety interaction had a very highly significant effect on grain yield per plant (Figure 3). At the low and medium N levels, variety H-688 had consistently higher grain yield per plant than P-304B. This is an indication that variety H-688 may be more efficient in utilizing low levels of N fertilizer than P-304B. There was a continuous reduction in grain yield per plant with higher plant density which was similar to trends described for many other yield components. According to Numez and Kamprath (1969), this linear reduction might have resulted from an increase in barreness, while Giesbrecht (1969) attributed it to shading. Early et al (1966) obtained a curvilinear reduction in grain yield per plant with shading, which reduced the rate of photosynthesis.

There was no significant difference in grain to whole plant ratio due to N rates in both seasons. As such, it appears that this ratio remained nearly constant. Moreover, similar mean ratios of 44.3% for the first crop and 44.6% for the second crop were obtained, indicating that grain to whole plant ratio was independent of season.

Decreasing area per plant significantly reduced the grain to whole plant ratio for both crops. This decrease was more pronounced in the second crop. Production of grain was enhanced at the low density while high density condoned more vegetative growth at the expense of grain production. Rutger and Crowder (1967) obtained similar results where the grain to whole plant ratio was 42.9% at 50,000 and 39.2% at 80,000 plants/ha.

Data presented in this study indicate that the grain to whole plant ratio was significant only for the first crop. Variety H-688 has a ratio of 46.6% as compared to 42.1% obtained for variety P-304B.

Grain to ear ratio was independent of N fertilizer rate, and was similar for the two seasons, but decreasing area per plant caused a reduction in this ratio. This effect was more pronounced in the second crop. Data presented here is contrary to report by Rutger and Crowder (1967) where they did not obtain differences in grain to ear ratio with variable plant density. This was attributed to the proportionate decrease of grain and cob weights of the ear at different plant population. Meanwhile the results of Bunting (1973) in which he obtained about 4 percent reduction in grain to ear ratio over a range of 6-20 plants/m^2 would lend support to the observations reported here.

Morphological Characteristics

Nitrogen rates significantly increased the stalk height and diameter of the two varieties. As spacing between plants increased so did height and diameter. Similar effects of plant density on height and stalk diameter have been reported by Rutger and Corwder (1967) and Giesbrecht (1968) who mainatained that shading of plants due to high population density gave rise to rapidly growing but weaker plants.

Ear leaf weight was increased with increasing N rate and area per plant for both varieties in the two growing seasons. The two varieties differed slightly during the first season, but P-304B had significantly heavier ear leaf than H-688 during the second season.

Number of ears produced per plant did not show any significant variation with different rates of nitrogen during both plantings. This is contrary to findings of Lang et al (1956) who obtained 33 percent barren stalks at 24,000 plants on the low nitrogen rate. Average number of ears produced was higher for the first crop than the second crop by 2 percent. This advantage could be partially responsible for the higher grain yield obtained in the first crop than the second crop.

Increasing plant density significantly reduced the number of ears produced per plant in both seasons. Barrenness for the second crop was 3% with 57,406 and 16% with 144,813 plants per hectare. In contrast, Giesbrecht (1969) obtained increases from 3% barrenness at 30,000 plants/ha to 15% at 75,000 plants/ha. Similar trends have been reported by Bunting (1973) and Robertson et al (1968) who obtained a generally linear (negative) response of number of ears produced per plant to decreasing area per plant.

Higher rates of nitrogen fertilizer did not cause a significant increase in plant lodging while closer plant spacing increased it. This is in agreement with earlier work by Nelson (1956). Variety H-688 was significantly more susceptible to lodging that P-304B. This could possibly be due to taller stalks or poorer root development of variety H-688. Robertson et al (1968) working with three hybrids observed more lodging with tall varieties than with short ones which they attributed to windy conditions during and immediately after tasselling. In this study average wind velocity of 16.1 km/hr was hardly severe enough to account for the high degree of lodging observed for variety H-688. But wind gusts may be the main reason for severe damage observed on susceptible varieties.

Plant mineral constituents

Ear Leaf

Leaf percent dry matter was found to be independent of N rate during the two seasons. There was a slight variation in the second crop due to spacing, where percent dry matter increased with the medium N level. The two varieties were generally similar but during the first crop leaf dry matter was higher in variety P-304B.

Leaf percent N was enhanced by increasing rates of N fertilizer in both seasons. These findings are in agreement with the results of Shukla (1972) and Dalal (1977). Walker and Peck (1973) reported an increase in ear leaf N, collected at early tasselling, with a range of 2.36 to 3.26% N with zero and 320 lb N/ac applications. They suggested that the application of N fertilizer provided additional N for the development of larger root system and more vigorous plant growth.

Based on the results illustrated in Figure 10, and yield data presented in Table 5, it is concluded that a range of 2.50-2.70% N in the ear leaf collected at early tasselling may be required for optimum yield. These values are lower than the range of 2.85 to 3.19% obtained in W. Nigeria and reported by Agboola (1972), but comparable to the findings of Melsted et al (1969). These differences could be ascribed to varietal differences and climatic conditions. Meanwhile the effect of spacing was evident only in the second crop where highest leaf percent N occurred with the highest area per plant.

Leaf P in both seasons was markedly increased by increasing rates of N applied from 102 0.28 to high 0.30%. Similar trends have been reported by Dalal (1977) who obtained increases in P uptake with increasing N rates.

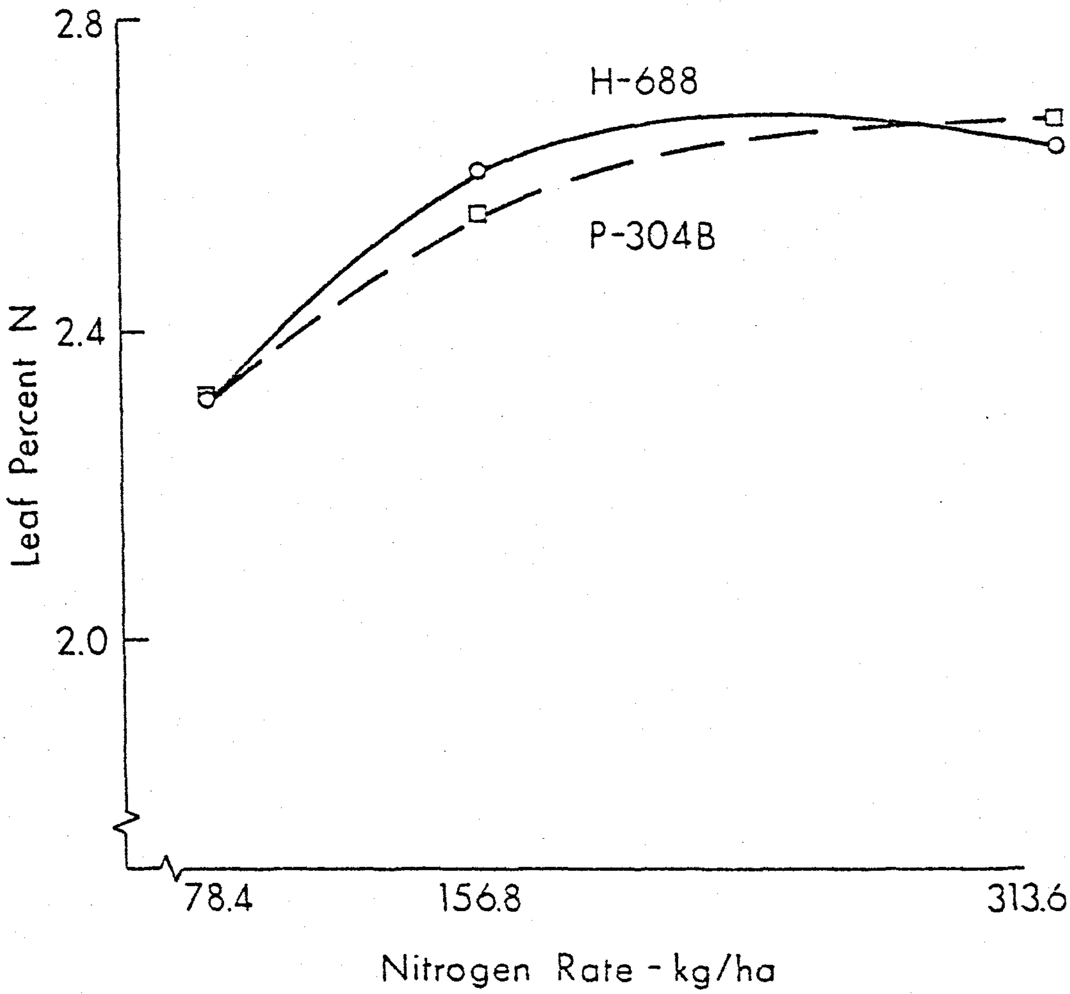

Fig. 10. The Effect of Nitrogen Fertilizer Rate on Leaf Total Nitrogen of Two Maize Varieties Grown in Two Seasons

Barber and Olson (1968) noted that high levels of N applied increased percent P and uptake of other nutrients. Increasing rates of N might have increased the solubility of fertilizer P or could have led to increased root activity of maize (Olsen and Dreier, 1956, and Terman et al, 1977). Meanwhile decreasing area per plant caused a decline in leaf percent P in the two seasons. On the average leaf percent P was lower in variety H-688 than in P-304B during the two seasons. This may indicate that variety H-688 which had higher yield is more efficient in utilizing soil P than variety P-304B.

In the two growing seasons, K levels were increased with higher rates of N fertilizer applications, while Ca and Mg levels increased only in the second crop. These trends in cationic uptake are in agreement with findings of several investigators (Cunningham, 1964; Bar-Yosef and Kafkafi, 1972; Terman and Allen, 1974; and Dalal, 1977). Increasing plant population density significantly reduced leaf K level during the first season and Ca during the second season, while Mg was not affected. When leaves of variety H-688 were compared with variety P-304B there were found to be significantly higher in Ca and Mg during the first season, and in K and Mg during the second season.

Leaf percent S increased markedly with increasing N rates applied in both seasons. The increases ranged from low .13 to high .15% in the first crop and from .13 to .16% in the second crop. These observations agreed with the findings of Rehm et al (1970). The N:S ratio in the leaves seems to remain nearly constant regardless of N-rates. The mean ratios calculated for the first and second crop were 18:1 and 17:1 respectively. On the other hand decreasing area per plant caused a drop in leaf S content. The N rate x spacing interaction was significant for the first crop only (Figure 7). It is of practical significance to note that leaf S increased with decreasing plant population density at the low and high N rates while it was not affected by spacing at the medium N fertilizer rate. There was a significant varietal difference in leaf S, where H-688 had higher content than P-304B.

At the high level of N fertilizer (313.6 kg/ha) leaf Si level was reduced significantly. This could possibly be due to dilution effect. Variety P-304B was found to accumulate higher levels of Si in the leaves than H-688, however, plant spacing had no significant effect on this element.

Increasing N-rate and area per plant caused significant increases in leaf Zn and Cu, while Mn level was not affected. Leaf Fe level increased with increasing N-rate during the first season only, while plant spacing had no significant effect on this element. Similar effects of N fertilizer on the uptake of the above elements have been reported by several investigators (Soltanpour, 1969; Walker and Peck, 1973; Terman and Allen, 1974; Bol'shakov et al, 1975; and Lutz et al, 1977). It was proposed that the acidifying effect of N fertilizer enhances the solubility of these nutrients in the root zone, thus increasing the plant uptake. The two varieties tested were significantly different in their leaf levels of Cu, Mn and Fe where variety H-688 had higher levels than P-304B. In addition there was a significant N rate x variety interaction which affected leaf Cu content (Figure 8). Cu levels in variety H-688 continuously increased with increasing N-rate, while in variety P-304B this element increased with the second increment of N and declined slightly at the highest N rate.

Forage

Percent dry matter in maize plants decreased significantly with increasing N fertilizer rate in the second crop, but this effect was not significant in the first crop. It is a well known fact that higher N rates contribute to increasing moisture content in plants as reported by Mason et al (1974). Plant population caused an increase in plant percent dry matter but this effect was significant only for the first crop. These findings are contrary to reports by Bunting (1973) where he found a decrease in percent dry matter with increasing plant population. While Rutgers and Crowder (1967), Mason et al (1974) and Phipps (1975) reported that plant spacing had no significant effect on forage percent dry matter. Due to the earlier maturity of variety H-688 as compared to P-304B, its percent dry matter was significantly higher than that of P-304B. The higher dry matter content of the second crop as compared to the first is due to the delay in harvesting which allowed it to advance in growth. This is in agreement with reports by Sherrod et al (1968).

Forage percent N increased significantly with increasing N rate in both seasons (Figure 11). This is in agreement with the findings of Robertson et al (1965), Parks et al (1970), Allen et al (1975) and others. Percent "recovery" of N applied as calculated from the forage yield and its percent N was found to decrease with increasing N fertilizer rate in the two seasons. For the first crop the "recovery" was 133.5, 82.1, and 44.8% respectively with applications of 78.4, 135.8, and 313.6 kg N/ha. Nitrogen "recovery" in the second crop for the above rates were 138.8, 91.5 and 48.2% respectively. Terman and Allen (1974) noted that N recovery by maize depended on N source and stage of growth. Using NH_4NO_3 and after 6 weeks of growth the recovery was 104, and 82% when they applied

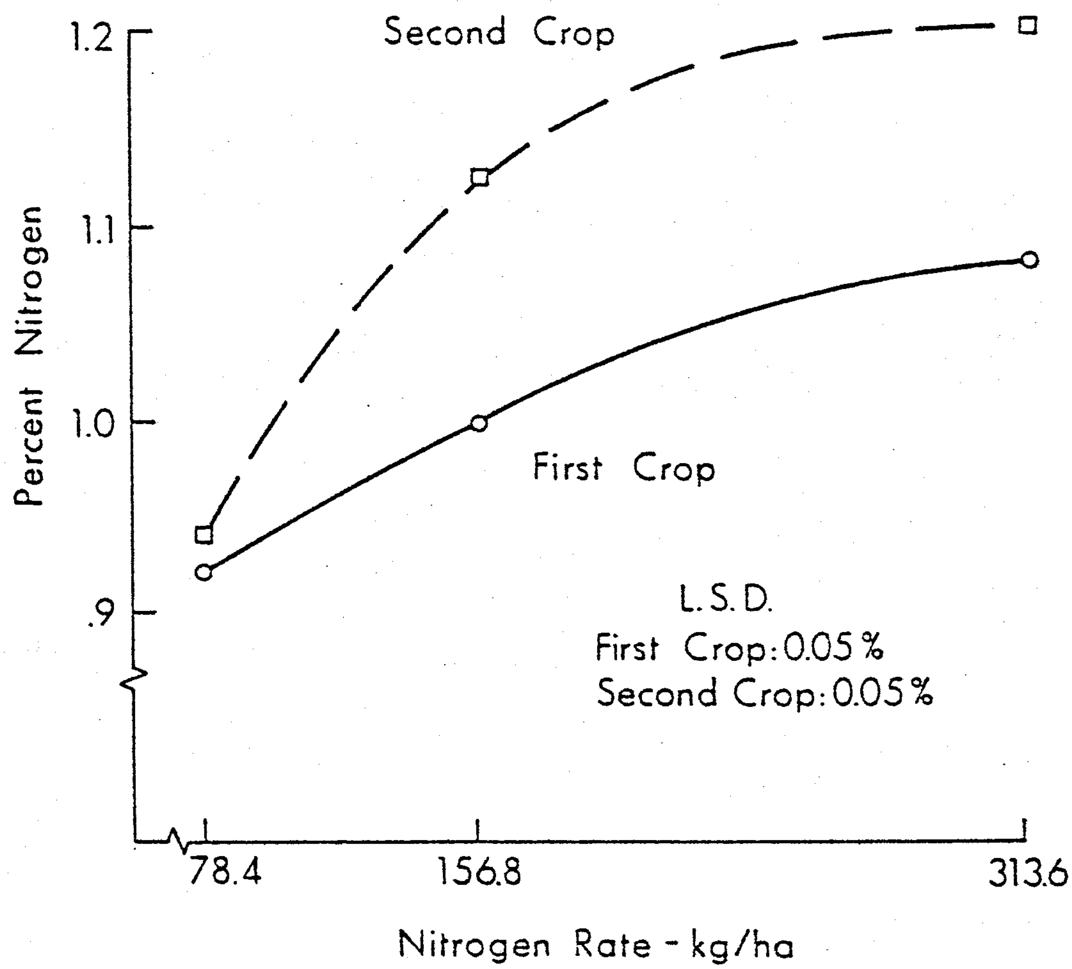

Fig. 11. The Effect of Nitrogen Fertilizer Rate on Forage Total Nitrogen of Forage Corn Grown in Two Seasons

300 and 1200 mg N per pot respectively. The high percent recovery at the low and medium rates of fertilization could be due to a) a substantial mineralization of soil N, b) presence of residual nitrogen from previous cropping, c) a low rate of N loss by leaching or volatization, d) the prevailing or optimum soil fertility conditions for plant growth which allowed efficient utilization of applied N fertilizer. Plant spacing did not have a significant effect on tissue N level in the two growing seasons, which is in agreement with findings of Lang et al (1956). Phipps in 1975 noted that increasing plant density led only to a slight reduction in forage percent N. However, the interaction of N rate x spacing significantly affected tissue N level during the first crop (Figure 9). At the high plant population density, 11.4 cm between plants, tissue percent N continued to increase with increasing N rate, while at the low population density, 22.9 cm spacing, the significant increase was between the low and the high N rate. At the medium spacing, 15.4 cm, N tissue level remained the same for the low and medium N rates but increased significantly at the high N rate. These results indicate that in order to retain forage with high level protein, at heavy plant density, high rates of N fertilizer will be required than at lower population density.

Tissue percent P was not affected significantly by N rate, plant density or variety, while Phipps and Pain (1975) concluded that forage percent P in maize was significantly decreased with increasing plant population density. They attributed this decrease to the keen competition between plants for limited nutrient availability. In the present study, and during the two growing seasons, maize plants are thought to have adequate supply of soil P based on soil levels suggested by Tamimi and Matsuyama (1977).

Forage percent K decreased with increasing N rate during the first crop, and due to increasing plant density in the two seasons. The two varieties had similar K content, but H-688 was higher than P-304B during the first season. Forage Ca percent was increased as N rate was raised from 78.4 to 156.8 or 313.6 kg/ha for the second crop only. Spacing had no significant effect while variety H-688 was consistently lower in tissue Ca than P-304B. Plant Mg levels were comparable in both varieties, while increasing N rate during the second season, caused a significant increase in this element. Plant Mg content was slightly decreased at medium plant spacing during the first crop, but was not affected by spacing during the second season.

Tissue S increased with the second increment of N fertilizer and remained at that level with the high N rate during the first crop. This increase was significant with each additional N fertilizer increment during the second crop (Figures 11 and 12). The range in S percent was 0.05 to 0.07%. The N:S ratio for the two crops varied but not consistently. Ratios as low as 16.5 and as high as 18.7 were obtained. These ratios are within the range of 10:1 to 20:1 required for balanced animal feed nutrition as suggested by Tisdale and Nelson (1975). The above N:S ratios are considerably higher than 11:1 reported by Sawarkar and Nayar (1975) for maize plants grown in a pot experiment. Terman et al (1973) suggested a ratio of 16:1 for corn at 6-8 weeks of age. Plant spacing had little effect on whole plant sulfur, with the exception of the first crop where its level was reduced at higher plant population. The N:S ratio for the first crop was 16.7, 19.4 and 20.0 in plants spaced 22.9, 15.4, and 11.4 cm spacing respectively: and 15.3, 15.7 and 15.4 for the above spacings for the second crop. Variety H-688 was consistently higher in

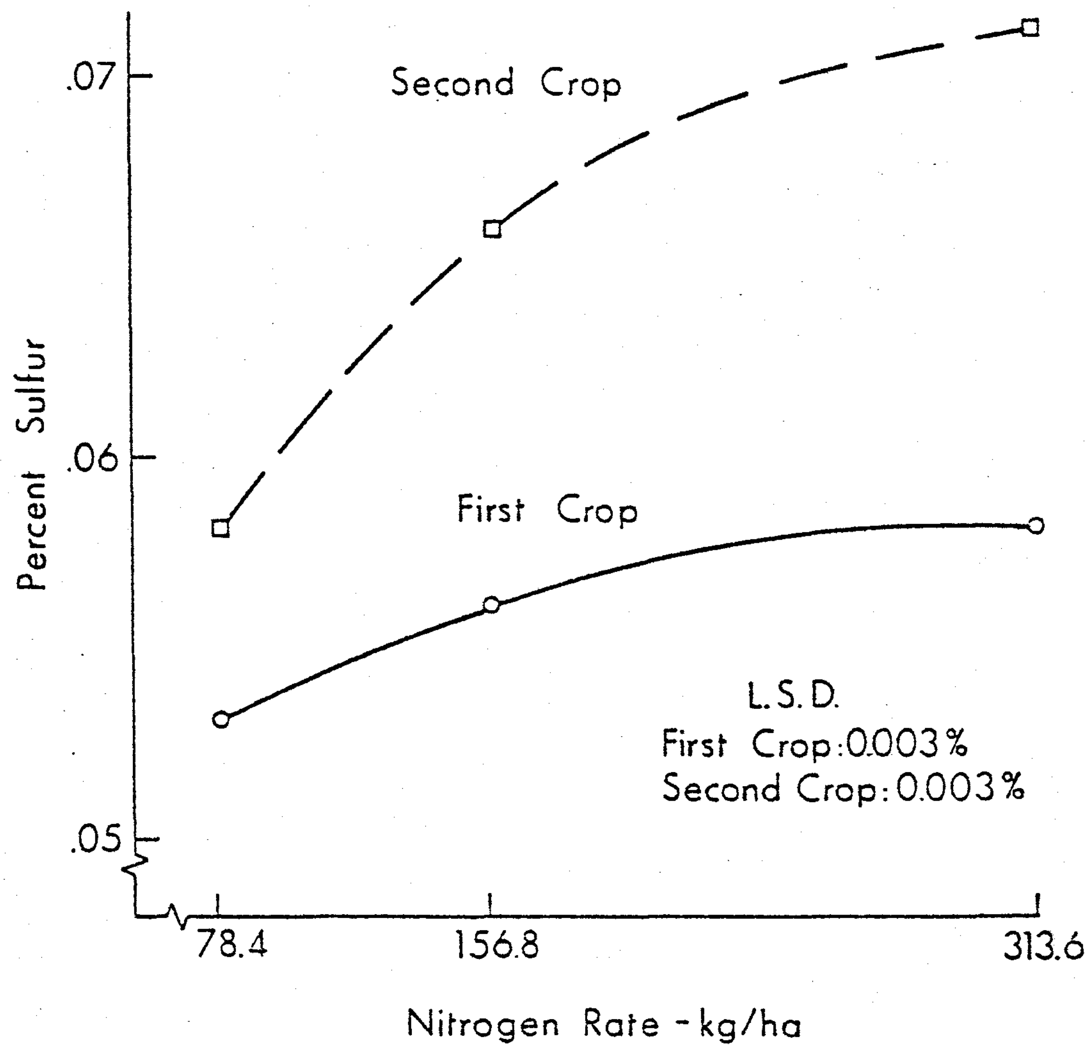

Fig. 12. The Effect of Nitrogen Fertilizer Rate on Forage Maize of Forage Corn Grown in Two Seasons

S than P-304B.

Plant Si was found to decrease with increase in N-fertilizer rate during the two seasons, which could be due to dilution effect. The difference was significant only during the first crop. Plant spacing had no significant effect, while variety H-688 was consistently lower in Si than P-304B.

Forage Zn and Fe levels were not affected by N fertilizer rate, while Cu was found to increase significantly with the highest N rate during both seasons. On the other hand, higher N rates caused an increase in the Mn level of the second crop. Terman and Allen (1974) and Walker and Peck (1973) reported enhancement of Mn uptake due to higher N rates. Plant population density was found to have significant effects on forage Cu, Mn, and Fe only during the first season. Cu was highest at the widest spacing, while Mn and Fe were highest at the closest spacing. There were some differences in the micronutrient levels of the forage of the two varieties, but these variations were not great. Variety H-688 was higher in Zn and Cu during the second season, while P-304B was higher in Mn during the first season.

When macro elements in the leaves and in the forage are compared, their levels were higher in the ear leaf than in the green forage. When the micronutrients are considered the leaves were higher in Zn and Cu while the forage was higher in Mn and Fe. The causes of these major differences have been either investigated or speculated upon by several researchers. Tukey (1970) noted loss of nutrients from amturing plants may be due to mechanical losses such as leaves, and leaching, while Emmet (1961) attributed this phenomenon to translocation of nutrients back into the roots. Terman and Allen (1974) noted decrease in root absorption capacity and diluting effects as reasons for these differences.

SUMMARY AND CONCLUSIONS

A field experiment was conducted to determine the effects of N fertilizer rates and plant spacing on yield and mineral constituents of two tropical maize varieties. The N levels were 78.4, 156.8, and 313.6 kg/ha. Plants were grown in 76.2 cm row spacing with 22.9, 15.4 and 11.4 cm between plants in the row. The experimental design was 3 N x 3 spacings x 2 varieties, complete factorial in a split plot with 4 replicates. Nitrogen and spacing were the main plots while variety was the subplot. The two tropical varieties were Pioneer 304B and University of Hawaii hybrid H-688. The location was at the Kohala Experimental Station at an elevation of 120 meters, on the Island of Hawaii. The soil belongs to the Kohala Series which is an Ustic Humitropept, Isohyperthermic of the order Inceptisols. Overhead supplemental irrigation was applied as needed to provide a total of 50 mm per week.

The experiment was conducted during two seasons. The first planting was on the 16th of March, 1977 followed by the second planting on the 3rd of August, 1977. Data were collected on grain and forage yield, and their components, on morphological characteristics, and on tissue mineral constituents of leaves and whole plant forage.

Maximum forage yields for the two varieties would be attained at about 200 kg N/ha in both seasons. On the average, yield was slightly higher in the first season (12.5 t/ha) than in the second season (12.3 t/ha). The first crop was grown during the season (March to August), which is usually considered best for Hawaii, because of its longer days and higher solar radiation. Decreasing area per plant was found to continuously increase the forage yield in both seasons, but yield per plant was lineraly decreased, probably due to increased stress and competition at higher plant densities. Variety H-688 was consistently slightly higher in forage yield than variety P-304B.

Grain yield increased with higher rates of N fertilizer. The data indicate that 200 kg N/ha would produce optimum yield. Mean grain yield was 6.7 t/ha for the first crop and 6.5 t/ha for the second crop. Plant spacing of 17.8 cm during the first season would produce optimum grain yield, while 22.9 cm spacing during the second season produced maximum yield. Yield of variety H-688 was 700, and 200 kg/ha higher than variety P-304B for the two seasons respectively.

Of the grain yield components investigated, a significant increase in ear weight and yield per plant was achieved by increasing nitrogen rates. Ratios of grain to whole plant and grain to ear were least affected by N rates, which appear to be genetically controlled and specific for each variety. However, these grain yield components were significantly reduced by increasing plant density. Ear weight, and grain yield per plant showed the greatest reductions.

Plant height and stalk diameter, both of which were higher for variety H-688, increased significantly with N rates. Increasing area per plant produced taller plants and larger diameters. Dry leaf weight was increased with increasing rates of nitrogen and decreased with increasing plant density, but variety P-304B had consistently higher leaf weight than H-688.

Number of lodged plants was not greatly increased by increasing N rates, which is contrary to the popular view that high nitrogen rates promote lodging. Decreasing area per plant, significantly promoted lodging in variety H-688 only. Variety P-304B was markedly more resistant to lodging than H-688, possibly because it had shorter stalks, better root development or was more tolerant to conditions promoting lodging.

Ear production per plant was significantly higher for variety H-688 and was affected more by increasing plant density than by N rates. On the average none of the varieties produced more than one ear per plant, and at the highest density 87 and 84% of the plants produced ears in the two seasons respectively.

Forage percent dry matter showed significant decline with increasing N rates, only in the second crop, but in the first crop increasing plant density considerably increased percent dry matter. Of the macro elements investigated in the forage, concentrations of total N, and S in both crops, K in the first crop, and Ca and Mg in the second crop, were enhanced by increasing N rates. Phosphorus was not affected while Si content was significantly reduced in the first crop. Similarly, the micronutrient concentrations of Cu in both crops, and Mn in the second crop only, were raised by increasing N rates. Its effect on the rest of the macro and micro elements was not significant. Plant recovery of applied N fertilizer was found to decrease with increasing N rate. For the first crop, the percent recovery was 133.5, 82.1 and 44.8% with applications of 78.4, 156.8 and 313.6 kg N/ha respectively. Percent N recovery for the above N rates in the second crop was: 138.8, 91.5, and 48.2% respectively. The N:S ratio in the forage was found to vary with variable N rates for the two crops, but not consistently. In the first crop increasing area per plant widened the N:S ratio from 16.7 at 22.9 cm spacing to 20.0 at the 11.4 cm spacing. While in the second crop, the ratio was nearly constant with a mean of 15.5.

Increasing plant density had no appreciable effect on forage percent N, P, Ca, Mg, and Si, but it caused a significant decline in K concentration for both crops and in S concentration for the first crop only. Among the micronutrients investigated, level of Cu was found to decline, while Mn and Fe increased with increasing plant density in the first crop, but no significant differences were found in the second crop.

There were significant differences between levels of several elements in the forage of the two varieties investigated. Variety H-688 was significantly higher than P-304B in percent N for the second season, in S (both crops), Zn and Cu (second crop), while levels of forage P and Mg was similar in both varieties during the two seasons. On the other hand, variety P-304B was significantly higher in Ca and Si (both crops), and K and Mn (first crop). Leaf percent dry matter was not influenced by N rates, but decreasing area per plant caused a significant increase in leaf dry matter only during the second crop.

As with forage, leaf total nitrogen was significantly increased by increasing N rates in both crops, but higher plant density reduced it significantly in the second crop. The critical leaf nitrogen concentration was between 2.50 and 2.70% for both varieties.

Similarly, leaf concentration of P, K and S were significantly enhanced by the increase in N rates in both seasons. Ca and Mg increased significantly only in the second season while Si concentration was lower at high N rates. Of the micro elements investigated, only Zn and Cu showed significant positive response to increasing N rates in both seasons, while an increase in Fe level was noted only in the first crop. The N:S ratio did not vary much with varying N fertilizer rates during the two seasons. The mean ratio for the first crop was 18.0, and 17.1

for the second crop.

In general, increasing plant density brought about significant reductions in leaf tissue concentrations of P, S, and Zn in both seasons; K, and Cu in the first season; Ca in the second, while Mg, Si, Mn, and Fe were not considerably affected. Leaves of variety H-688 had significantly higher levels of Ca, Mg, S, Cu and Fe, but was lower in P, Si and Zn than variety P-304B.

Finally there is sufficient evidence from this study that forage production could still be increased at higher plant densities under optimum management conditions. But the associated mineral composition and grain yields may be greatly reduced which are critical factors in determining forage quality.

Table 23. Soil Profile Description

KOHALA SILTY CLAY

Location: Island of Hawaii, Hawaii County, Hawaii. Hawi Quadrangle-- 20°14'30" north latitude and 155°49'50" east longitude. Pit located about 300 m (1,000 feet) N. of Hawi Town in field Alaalae 4, Kohala Sugar Company. Date of sampling: April 6, 1965.

Description by: H. Sato and L. D. Giese. Collectors: K. Flach, L. Swindale, L. Giese, H. Sato, R. Smythe, G. Yamamoto, and W. Subica.

Classification: Ustic Humitropept, very fine, mixed, isohyperthermic.

Vegetation: Sugarcane (*Saccharum officinarum*), natural vegetation consists of koa haole (*Leucaena glauca*), lantana (*Lantana camara*), guava (*Psidium guayava*), and Christmas berry (*Schinus terebinthifolius*). Climate: Average annual precipitation is 125 cm (50 inches). The mean annual temperature is 23°C (73°F). Parent material: Basalt influenced by volcanic ash. Topography: Windward foot slopes of Kohala Mountain. Slope gradient 2 percent; convex slope; north aspect. Elevation: 165 m (550 feet). Drainage: Well drained; moderately rapid permeability; medium runoff. Soil moisture: Moist.

Remarks: Textures are apparent field textures. Texture and terms for describing "smeariness" are explained in the methods section of this report. Paired sample number S65Ha-1-4.

HORIZON	DESCRIPTION
Apl RSL No. 6567	0 to 18 cm (0-7 inches), very dark grayish brown (10YR 3/2) silty clay, dark grayish browm (10YR 4/2) dry; moderate fine granular structure; extremely hard, friable, sticky and plastic; many roots; many fine poores; moderate effervescence

with hydrogen peroxide; slightly acid (pH 6.3); abrupt smooth boundary.

Ap2 RSL No. 6568	18 to 35 cm (7-14 inches), dark brown (10YR 3/3) silty clay, dark grayish brown (10YR 4/2) dry; weak coarse prismatic breaking to moderate medium and fine subangular and angular blocky structure; very hard, friable, sticky and plastic; many roots along prism faces; very compact in place; common pressure cutans; manganese coatings on root channels; common very fine red rock fragments; moderate effervescence with hydrogen peroxide; slightly acid (pH 6.4); abrupt smooth boundary.
B21 RSL No. 6569	35 to 68 cm (14-27 inches), dark brown (10YR 3/3) silty clay loam, (10YR 4/3) dry; moderate medium and coarse subangular blocky breaking to moderate fine subangular blocky structure; hard, friable, slightly sticky and plastic; few roots; many very fine pores; very compact in place; few pressure cutans; weak effervescence with hydrogen peroxide; slightly acid (pH 6.5); gradual smooth boundary.
B22 RSL No. 6570	68 to 98 cm (27-39 inches), dark yellowish brown (10YR 3/4) silty clay, dark brown (10YR 4/3) dry; strong fine and very fine subangular blocky structure; hard, friable, sticky and plastic; few roots; few thin patchy cutans; few saprolite gragments; few manganses coatings; no effervescence with hydrogen peroxide; neutral (pH 6.6); clear smooth boundary.
C1 RSL No. 6571	98 to 113 cm (39-45 inches), variegated colors; saprolite; firm; nonsticky and nonplastic; weakly smeary; no roots; no effervescence with hydrogen peroxide; neutral (pH 6.8);

	gradual wavy boundary.
C2 RSL No. 6572	113 to 133 cm (45-53 inches), variegated colors; saprolite; firm; nonsticky, nonplastic and weakly smeary; no roots; no effervescence with hydrogen peroxide; neutral (pH 6.9).

Table 24. Soil analyses of experimental plots*

N Rate kg/ha	Spacing (cm)	Prior to Planting ppm					Post First Crop ppm					Post Second Crop ppm				
		pH	P	K	Ca	Mg	pH	P	K	Ca	Mg	pH	P	K	Ca	Mg
78.4	22.9	6.0	85	283	2100	330	5.9	81	249	2040	314	5.9	72	231	1575	323
	15.4	6.1	94	294	2240	319	5.9	87	220	2140	306	6.0	74	207	1680	311
	11.4	6.0	87	300	2280	315	5.9	74	227	2140	264	5.8	76	227	1590	284
156.8	22.9	6.0	92	302	2180	320	5.9	75	327	2120	305	6.1	79	233	1725	315
	15.4	5.9	81	261	2180	321	5.8	70	207	1980	291	5.9	64	180	1560	303
	11.4	6.0	84	261	2000	310	5.7	71	192	1880	283	5.8	67	194	1545	268
313.6	22.9	6.0	77	288	2060	315	5.9	74	228	2060	300	6.0	73	320	1620	316
	15.4	6.0	86	273	2190	314	5.9	79	213	2040	294	6.0	81	225	1620	311
	11.4	6.0	84	276	2120	318	5.7	75	213	1960	288	5.8	70	218	1530	284

*Data reported are means of 4 replicates.

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